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Permit Writers' Guidance Manual for Hazardous Waste Tanks

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The purpose of this manual is to provide a resource for permit writers in the implementation of Part 264, Subpart J, CFR, which sets forth regulations for facilities that use tanks to treat or store hazardous waste. The material is meant for guidance purposes only and is not meant to replace data and information that are specific to the facility being assessed. This manual has been written primarily to assist permit writers when performing a technical review of Part B permit applications for facilities that treat or store hazardous waste in tanks and when writing the final permit. The most likely user would be either an engineer or a scientist with some experience in reviewing engineering information.

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on

PERMIT WRITERS' GUIDANCE MANUAL FOR HAZARDOUS WASTE TANKS

to

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION II

from

BATTELLE
Columbus Division
505 King Avenue
Columbus, Ohio 43201

EPA Contract 68-01-6515
WA 02-004

A-86-00076

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PREFACE

This Working Draft of the "Permit Writers' Guidance Manual for Hazardous Waste Tanks" was developed to provide guidance to the permit reviewer in evaluating the design of hazardous waste tanks, piping, controls, and ancillaries (containment measures, vents, etc.). The manual is aimed at presenting supporting material where possible within the manual or, alternatively, offering summaries or indications of content and coverage of the extensive technical material contained in existing standards, codes, handbooks, etc.

Because of the wide spectrum of tank characteristics and applications anticipated to be encountered by the permit reviewer, the content of this document contains a diversity of subject matter. Some of the content was selected for coverage on the basis of comments from Regional Offices contacted as the first step in the preparation of this manual. The format and arrangement of the draft manual have been selected with the aim of allowing for addition of supplementary material by the individual user and possibly the incorporation of uniform changes and additions at some future time.

Similarly, each section contains a detailed listing of content intended as an aid in assessing material as different requirements arise.

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CHAPTER CONTENTS

1.0 USE AND ORGANIZATION OF THE MANUAL
  1.1 How to Use the Manual
  1.2 Manual Organization
  1.3 References, Codes, and Handbooks

1.0 USE AND ORGANIZATION OF THE MANUAL

The purpose of this manual is to provide a resource for permit writers in the implementation of Part 264, Subpart J, of Code of Federal Regulations, which sets forth regulations for facilities that use tanks to treat or store hazardous waste. The material is meant for guidance purposes only and is not meant to replace data and information that are specific to the facility being assessed.

More specifically, this manual has been written primarily to assist permit writers when performing a technical review of Part B permit applications for facilities that treat or store hazardous waste in tanks and when writing the final permit. While this manual was not primarily designed to support the activity of a "completeness check", the regulatory analysis (i.e., an itemized breakdown of regulatory requirements) given in Appendix A can be used as a support item in a completeness check.

In general, it has been assumed that the most likely user of the manual would be either an engineer or a scientist with some experience in reviewing engineering information. Nevertheless, other professionals could probably make significant use of the manual if engineering associates were available for consulting.

1.1 How to Use the Manual

This manual can be used only in conjunction with a reference library of various standards, codes, handbooks, data surveys, and other literature—conceptually the manual could be called "Volume I" and should be expected to make frequent reference to documents in a reference library that could be called "Volume II' for further details. However, nearly all of the reference library is copyrighted material that cannot be legally integrated into a real "Volume II".

The subject of tank permitting has many aspects about which the permit writer should be aware, ranging from systems, tank types, controls, auxiliaries, foundations and supports, inspections, spills and containment, hazardous mixtures, deterioration , to regulations. To assist the permit writer, these subjects have been subdivided into discrete subject areas under a large number of subject headings.

Only major headings are presented in the main Table of Contents at the beginning of the manual; this will allow the permit writer to quickly scan the main Table of Contents to determine the chapter in which the desired material is likely to be found, and go directly to the appropriate chapter. Each chapter containing three or more levels of headings has its own detailed chapter Table of Contents showing both the major and the minor headings. The detailed chapter outline will allow the permit writer to determine the specific section number in which the desired information is located. (Note: Conventional page numbers are not used to allow easy insertion, without pagination problems, of either new or revised material as it is developed by the permit writers themselves, or in response to their needs; it is hoped that this manual will become a "living" document.)

1.2 Manual Organization

The manual is organized assuming that the permit writer will have identified technical areas for which he needs guidance. The overall scheme of the manual is as follows:

- The general relationship of tanks to the rest of the facility is presented first in Chapter 2.
- Standard new metal tanks are presented next in Chapter 3, and all other types of tanks are presented in Chapter 4.
- Tank ancillaries are presented in Chapters 5, 6, and 7.
    - Chapter 5. Pressure and Other Control Systems
    - Chapter 6. Pumps, Piping and Stuffing Boxes
    - Chapter 7. Foundations, Supports, Insulation and Grounding
- Required inspections of tanks are discussed in Chapter 8.
- Chapter 9 contains a discussion of spills and leaks and secondary containment as these pertain to tanks from both a regulatory and practical viewpoint.
- Chapter 10 contains a discussion of problems that may occur upon mixing of various hazardous wastes.

- A concise regualtory analysis is presented as Appendix A for quick reference by the permit writer.
- A discussion about corrosion and deterioration of various materials of construction is presented in Appendix B.

Even though thought was given to the manual's outline, problem areas did arise in attempting to formulate and use an outline. Although an effort was made to categorize the information presented into discrete sections of the manual with a minimum amount of cross references, some cross referencing was necessary to avoid excessive redundancy. Some of the consequences are as follow:

- Permit writers will not have to refer to Chapter 4 if only new standard metal tanks are being permitted. However, reference to both Chapters 3 and 4 will probably be required if used metal tanks are involved.
- Inspection of fiberglass-reinforced plastic tanks is covered in Chapter 4 even though Chapter 8 is titled "Inspections".

Some chapters and appendices have not been completed. Nevertheless, in most cases some information was available from a similar manual previously prepared by Fred C. Hart Associates, Inc., and this information was inserted where appropriate. Examples are as follow:

"Pumps" in Chatper 6
"Spills and Leaks" and "Secondary Containment" in Chapter 9
"Reactions in Tanks" in Chapter 10

1.3 References, Codes, and Handbooks

As stated, this Manual serves as a "bridge" to the extensive technical background possibly required in consideration of issuing a permit for a tank. This manual cannot include all technical background which might be required for specific cases because of the volume of such material and because some of the material is covered by copyright restrictions. However, in developing this manual, some reference materials were judged to be more often used than others. The reference materials relevant to tanks is listed in Table 1-1 with an indication of the estimate of the likely importance of the reference material in the activity of permit review.

TABLE 1-1. REFERENCES FOR USE WITH THE PERMIT GUIDANCE MANUAL FOR HAZARDOUS WASTE TANKS

Reference	Subject (Short Form)	Primary Reference	Optional Reference	Seldom Used Reference
API 620	Low pressure tanks	x		
API 640	Atmospheric pressure tanks	x		
NFPA 30	Flammable liquids	x		
API 12B	Bolted tanks			x
API 12D	Large tanks			x
API 12F	Small tanks	x		
API 12A	Riveted tanks			x
ANSI 1396.1	Aluminum tanks			x
UL 142	Aboveground "gas" tanks	x		
UL 58	Underground "gas" tanks	x		
ASME Section VIII	Pressure vessels		x	
API Guide for Inspecting Refinery	Equipment			
Chapter XIII	Tanks - low pressure	x		
Chapter II	Conditions causing failures	x		
Chapter IV	Inspection tools		x	
Chapter V	Safe practices		x	
Chapter XV	Instruments		x	
Chapter XVI	Pressure relieving devices		x	
Other Chapters	(miscellaneous)			x
ASTM D4021-81	Fiberglass-reinforced tanks	x		
UL 1316 (tentative)	Fiberglass-reinforced tanks			x
ACI Manual of Concrete Practice			x	
ACI 318	Reinforced concrete		x	
ACI 350	Sanitary engineering practice		x	
ACI 201.1 R-68	Condition of concrete			x
ACI 311-75	Inspection of concrete			x
API 2000	Tank venting		x	
ANSI B 31.3	Refinery piping		x	
ANSI B 31.4	Transport piping			x
NACE - Corrosion Data Survey	Metals Section	x		
	Non-Metals Section	x		
NFPA 31	Oil-burning equipment			x
Perry's Handbook	Chemical engineering	x		
Mark's Handbook	Mechanical engineering	x		
NFPA 77	Static electricity		x	
Petroleum Process Handbook			x	

REFERENCES

"Welded Steel Tanks for Oil Storage", API Standard 650, Seventh Edition, November 1980; American Petroleum Institute, 2101 L Street Northwest, Washington, D.C. 20037.

"Standard for Glass-Fiber-Reinforced Underground Storage Tanks for Petroleum Products - UL 1316" (draft, January 1982), Underwriters Laboratories, Inc., 333 Pfingsten Road, Northbrook, Illinois 60062.

"Flammable and Combustible Liquids Code, NFPA30-1981", National Fire Protection Association, Batterymarch Park, Quincy, Massachusetts.

"Guide for Inspection of Refinery Equipment", American Petroleum Institute, Washington, D.C.

"Metals Section - Corrosion Data Survey", Fifth Edition, National Association of Corrosion Engineers, Houston, Texas, 1974.

"Non-Metals Section - Corrosion Data Survey", Fifth Edition, National Association of Corrosion Engineers, Houston, Texas, 1975.

"Mark's Standard Handbook for Mechanical Engineers", Eighth Edition, McGraw-Hill Book Company, New York.

"Petroleum Processing Handbook", W.F. Bland and R.L. Davidson, McGraw-Hill Book Company, New York, 1967.

"Chemical Engineers' Handbook", Fifth Edition, R.H. Perry and C.H. Chilton, editors, McGraw-Hill Book Company, New York, 1973.

"Manual of Concrete Practice", American Concrete Institute, Detroit, Michigan, 1979.

"Standard Specification for Glass-Fiber-Reinforced Polyester Underground Petroleum Storage Tanks - ASTM D4021-81", American Society for Testing and Materials, Philadelphia, Pennsylvania, 1981.

American Society of Mechanical Engineers 1980 Boiler and Pressure Vessel Code - Section VIII - Pressure Vessels. New York, 1980.

"American National Standard for Welded Aluminum-Alloy Storage Tanks, ANSI B96.1-1981", American National Standards Institute, 1430 Broadway, New York City, New York 10018.

"Oil Storage Tanks with Riveted Shells", API Standard 12A, Seventh Edition, March, 1941 (reissued September, 1951), American Petroleum Institute, New York City, New York.

"Petroleum Refinery Piping - ANSI B31.3 - 1973", The American Society of Mechanical Engineers, 345 East 47th Street, New York, New York 10017.

"Liquid Petroleum Transportation Piping Systems - ANSI B31.4 - 1974"; The American Society of Mechanical Engineers, 345 East 47th Street, New York City, New York 10017.

"Steel Underground Tanks for Flammable and Combustible Liquids - UL 58", Seventh Edition, April 1981; Underwriters Laboratories, Inc., 333 Pfingsten Road, Northbrook, Illinois 60062.

"Recommended Rules for Design and Construction of Large, Welded, Low-Pressure Storage Tanks", API Standard 620, Seventh Edition, September 1982; American Petroleum Institute, 2101 L Street Northwest, Washington, D.C. 20037.

"Steel Above-Ground Tanks for Flammable and Combustible Liquids - UL 142", Fifth Edition, 1982, Underwriters Laboratories, Inc., Northbrook, Illinois.

"Recommended Practices on Static Electricity - NFPA Code 77", National Fire Protection Association, Quincy, Massachusetts.

CHAPTER CONTENTS

2.0 GENERAL PROCESS CONSIDERATIONS

- 2.1 Process Flow Diagram (PFD)
- 2.2 Piping and Instrumentation Diagram (P&ID)
- 2.3 Classification of Hazardous Wastes
- 2.4 Installation of Outside Above-ground Tanks

2.0 GENERAL PROCESS CONSIDERATIONS

The general process considerations presented in this chapter relate broadly to overall systems factors and cover those subject areas that do not fit well into other more specific sections of this manual. Hence, the subject areas have covered a general theme. Process flow diagrams (PFD)*, piping and instrumentation diagrams (P&ID)*, classification of liquids and hazardous waste (HW), and buffer zone or installation of outside above-ground tanks are addressed here.

2.1 Process Flow Diagram (PFD)

A review of a process flow diagram and associated text may serve, depending on the method selected by the originator for presentation of information, to supply certain required information relevant to the requirements to be satisfied in terms of a tank, its design, and its probable performance. The process may consist of a single source of waste, one input line, and one outlet. The associated diagram could be correspondingly simple. Alternatively, the process flow diagram may show the overall plant processes and/or sources of a number of wastes and their corresponding routing to waste storage or treatment processes. The process flow diagram may thus be of interest in terms of gaining an understanding of the role of one or more waste storage tanks in terms of overall plant operations.

An example of a process flow diagram is given in Figure 2-1. In this particular example the information of interest is that for the spent oil tank and includes direction of flow, operating temperature and pressure, size and indication of data listings of interest, i.e., 10, 12, and 14 in the mass balance table included on the flow diagram.

The process flow diagram should be reviewed to obtain a general orientation to the hazardous waste management system for the plant and is a possible source or location of data for any of the following factors:

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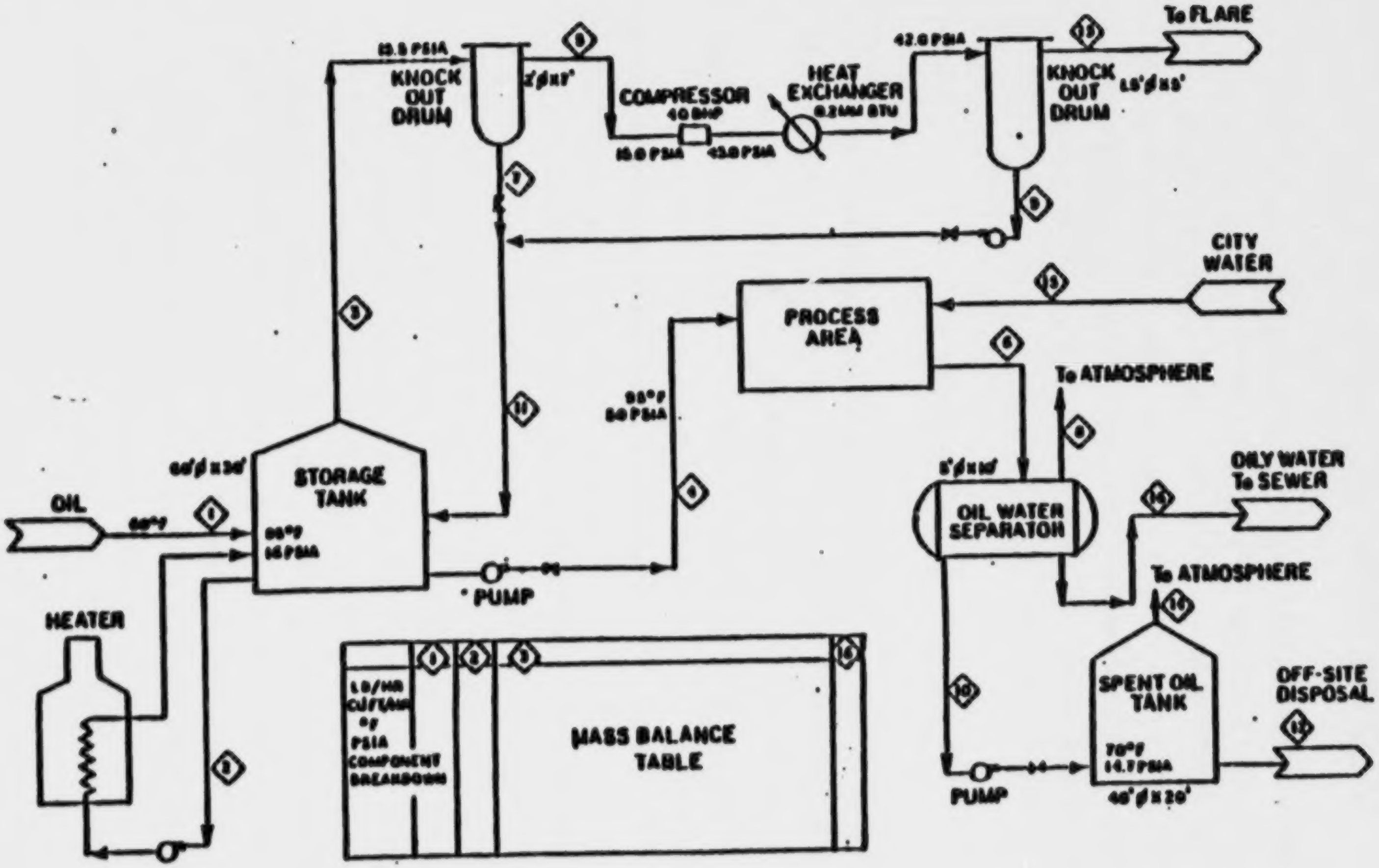
*According to 270.16 (Specific Part B information requirements for tanks), Applicants " . . . must provide . . . (d) A diagram of piping, instrumentation, and process flow."


KNOCK OUT DRUM
COMPRESSOR
40 BHP
16.0 PSIA
42.0 PSIA
HEAT EXCHANGER
42.0 PSIA
KNOCK OUT DRUM
To FLARE
CITY WATER
PROCESS AREA
To ATMOSPHERE
OIL
STORAGE TANK
PUMP
HEATER
OIL WATER SEPARATOR
OILY WATER To SEWER
To ATMOSPHERE
SPENT OIL TANK
70°F
14.7 PSIA
OFF-SITE DISPOSAL
PUMP
LB/HR
°F
PSIA
COMPONENT BREAKDOWN
MASS BALANCE TABLE

Source: Fred C. Hart Associates, INc., 1980

FIGURE 2-1. A SIMPLE PROCESS FLOW DIAGRAM

1. Basis for sizing the tanks (see 3.1.2)
2. Mass balance between inlet and outlet stream
3. Direction of waste stream flow
4. The possibility of mixing incompatible wastes or their placement in tanks of inappropriate materials of construction
5. Each item of major equipment (grouping duplicate items together)
6. The identifying number, name, material of construction, and critical dimensions, performance requirement, and capacities for each item or group of duplicate items
7. The required pressure and temperature conditions for each item or group of items
8. The flow rate, composition, specific gravity, molecular weight, and properites of each process stream
9. The flow rate and conditions of supply for steam, cooling water, and other utilities
10. Batch sizes and operating cycles for batch processes.

All of the above information should appear on the PFD. However, there may be some variations in the preparation of PFDs by the applicants. Some of the supporting information such as items 1, 4, 9, and 10 may be given in the text or on a separate sheet or drawing; but items 2, 3, 5, 7, and 8 may be given in the PFD. The PFD does not usually include valves and pipe fittings, but it may show major control schemes.

2.2 Piping and Instrumentation Diagram (P&ID)

P&IDs are drawings with details of piping and instruments. These drawings are useful to the process or project engineer for reviewing the adequacy of design for fail-safe operation of process equipment. A P&ID drawn specifically for a tank should contain the following information:

- Each tank with its identification number
- Each process pipe with its identification number, material of construction, pressure rating code, and size

- Each valve, by means of a symbol that indicates the valve type (a code for the symbols should be provided)
- Steam tracing (or jacketing) and steam traps
- All instruments and interconnections between instruments and controls.

Important items on the P&ID that should be reviewed in accordance with subsequent sections of this manual by a permit writer regarding tanks include:

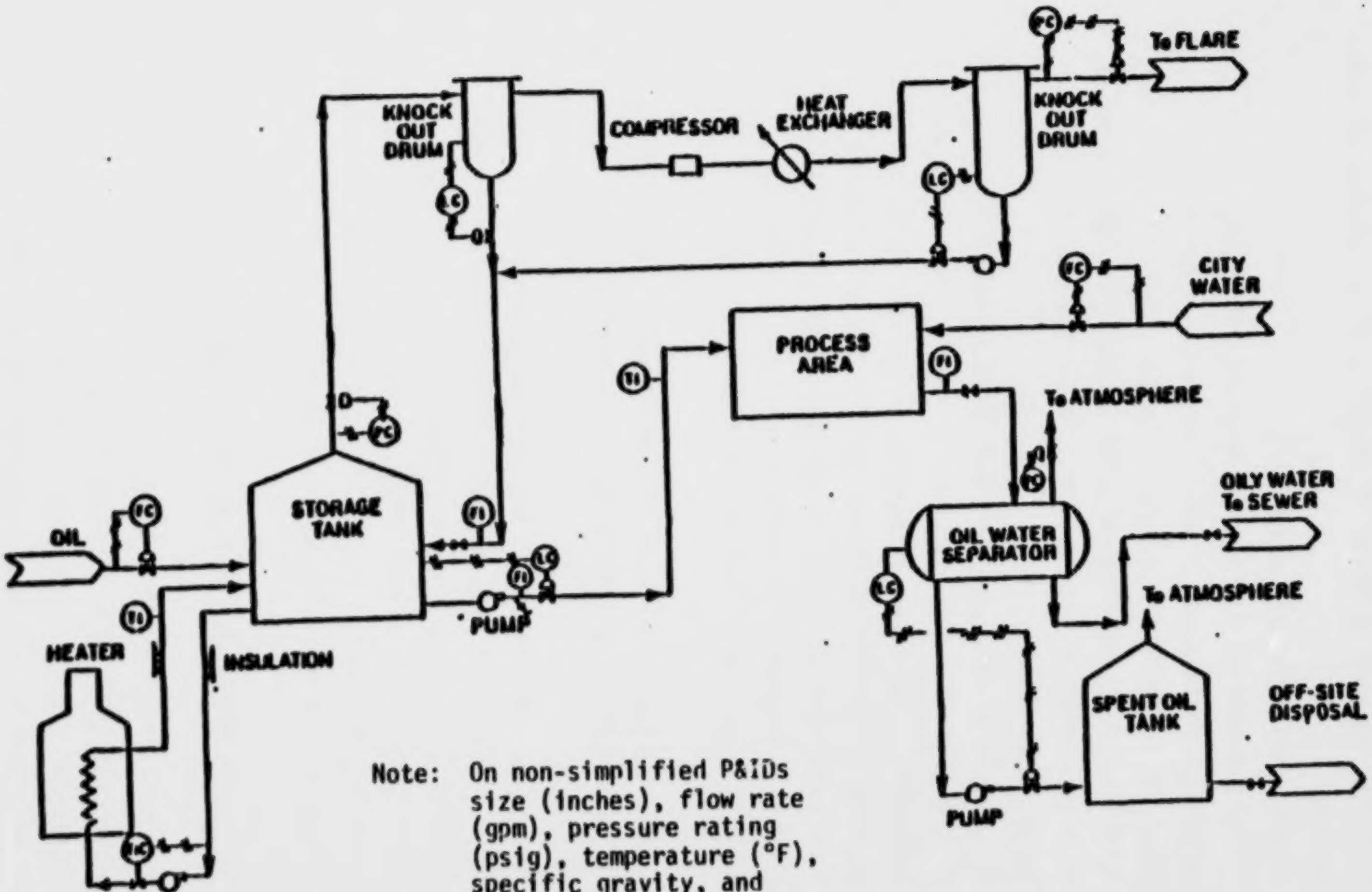
- Level controls
- Pressure controls or vents
- Adequacy of controls to assure that no mixing of incompatible wastes would occur
- Adequacy of the size of control and vent valves
- Adequacy of the pipe sizes
- Material of construction for valves and piping
- Types of instruments (manual or automatic).

An example of a simplified P&ID for a storage tank is given in Figure 2-2. It should be noted that the discussion above postulates that the applicant would provide a normal P&ID including all of the required information indicated, because a complete P&ID would normally be the most convenient form of presentation. However, much of the information required by the permit writer could be presented in alternative formats.

2.3 Classification of Hazardous Wastes

Waste liquids or aqueous solutions are normally stored in tanks or containers. These liquids may be classified as hazardous or non-hazardous types. If the liquids exhibit any characteristics of ingitability, corrosivity, reactivity, or EP toxicity, they are classified as hazardous waste. These hazardous waste characteristics are defined in 40 CFR 261.20 through CFR 261.24.

A liquid or aqueous solution is considered corrosive if its corrosivity toward a specific material is greater than 6.35 mm per year or its pH outside the range of 2 to 12.5.


KNOCK OUT DRUM
COMPRESSOR
HEAT EXCHANGER
KNOCK OUT DRUM
PC
To FLARE
LC
LC
CITY WATER
FC
PROCESS AREA
FI
TI
To ATMOSPHERE
PC
PC
STORAGE TANK
OIL
FC
TI
FI
FI
LC
PUMP
HEATER
INSULATION
TC
OIL WATER SEPARATOR
OILY WATER To SEWER
To ATMOSPHERE
LC
SPENT OIL TANK
OFF-SITE DISPOSAL
PUMP

Note: On non-simplified P&IDs size (inches), flow rate (gpm), pressure rating (psig), temperature (°F), specific gravity, and materials of construction will be indicated adjacent to each pipe.

Source: Fred C. Hart Associates Inc., 1980

FIGURE 2-2. A SIMPLIFIED PIPING AND INSTRUMENTATION DIAGRAM

A liquid or aqueous solution is reactive if it has any of the following properties.

- Reacts violently with water
- Forms a potentially explosive mixture with water
- Generates toxic gases, vapors, or fumes in sufficient quantity to present a danger to human health
- Is a cyanide- or sulfide-bearing waste which, when exposed to a pH condition between 2 and 12.5, can generate toxic gases, fumes, or vapors.
- Is capable of detonation of explosive reaction if subjected to strong initiating source or if heated under confinement
- Is readily capable of detonation or explosive reaction or decomposition at standard temperature and pressure
- Is a forbidden explosive as defined in 49 CFR 173.51, or a class A explosive as defined in 49 CFR 173.53, or a class B explosive as defined in 49 CFR 173.88.

A liquid or aqueous solution is considered to exhibit toxicity if a representative sample of the waste has the characteristics as indicated in 40 CFR 261.24.

A liquid or aqueous solution has the characteristic of ignitability if it has a flash point less than 60 C (140 F). The National Fire Protection Association _Flammable and Combustible Liquids Code_ (NFPA 30-1981) has information on how these liquids are further classified.

Information about other important physical and chemical properties of hazardous wastes is given in Section 3.1.2.

2.4 Installation of Outside Above-Ground Tanks

The National Fire Protectin Association (NFPA) in its _Flammable and Combustible Liquids Code_, NFPA 30-1981, presents buffer zone requirements for the location of tanks with respect to property lines, public ways, important buildings on the same property, and also requirements for the spacing between any two adjacent above-ground tanks. These requirements are specifically related to tanks storing flammable and combustible liquids.

Examples of these NFPA spacings are given in the following tables (2-1 through 2-6).

Table 2-1. STABLE LIQUIDS (OPERATING PRESSURE 2.5 psig OR LESS) (17.24 kPa)

Type of Tank	Protection	Minimum Distance in Feet from Property Line Which Is or Can Be Built Upon, Including the Opposite Side of a Public Way and Shall Be Not Less Than 5 Feet	Minimum Distance in Feet from Nearest Side of Any Public Way or from Nearest Important Building on the Same Property and Shall Be Not Less Than 5 Feet
Floating Roof [See 2-2.1.1(a)]	Protection for Exposures*	½ times diameter of tank	⅙ times diameter of tank
	None	Diameter of tank but need not exceed 175 feet	⅙ times diameter of tank
Vertical with Weak Roof to Shell Seam (See 2-2.1.1)	Approved foam or inerting system on tanks not exceeding 150 feet in diameter**	½ times diameter of tank	⅙ times diameter of tank
	Protection for Exposures*	Diameter of tank	⅓ times diameter of tank
	None	2 times diameter of tank but need not exceed 350 feet	⅓ times diameter of tank
Horizontal and Vertical with Emergency Relief Venting To Limit Pressures to 2.5 psig	Approved inerting system on the tank or approved foam system on vertical tanks	½ times Table 2-6	½ times Table 2-6
	Protection for Exposures*	Table 2-6	Table 2-6
	None	2 times Table 2-6	Table 2-6

SI Units: 1 ft = 0.3048 m.

*See definition for "Protection for Exposures."

**For tanks over 150 ft in diameter use "Protection for Exposures" or "None" as applicable.

Reprinted with permission from NFPA 30-1981, Flammable and Combustible Liquids Code, Copyright© 1980, National Fire Protection Association, Quincy, Massachusetts 02269. This reprinted material is not the complete and official position of the NFPA on the referenced subject, which is represented only by the standard in its entirety.

TABLE 2-2. STABLE LIQUIDS (OPERATING PRESSURE GREATER THAN 2.5 psig) (17.24 kPa)

Type of Tank	Protection	Minimum Distance in Feet from Property Line Which Is or Can Be Built Upon, Including the Opposite Side of a Public Way	Minimum Distance in Feet from Nearest Side of Any Public Way or from Nearest Important Building on the Same Property
Any Type	Protection for Exposures*	1½ times Table 2-6 but shall not be less than 25 feet	1½ times Table 2-6 but shall not be less than 25 feet
	None	3 times Table 2-6 but shall not be less than 50 feet	1½ times Table 2-6 but shall not be less than 25 feet

SI Units: 1 ft = 0.3048 m.

*See Definition for "Protection for Exposures."

TABLE 2-3. BOIL-OVER LIQUIDS

Type of Tank	Protection	Minimum Distance in Feet from Property Line Which Is or Can Be Built Upon, Including the Opposite Side of a Public Way and Shall Be Not Less Than 5 Feet	Minimum Distance in Feet from Nearest Side of Any Public Way or from Nearest Important Building on the Same Property and Shall Be Not Less Than 5 Feet
Floating Roof [See 2-2.1.1(a)]	Protection for Exposures*	½ times diameter of tank	⅙ times diameter of tank
	None	Diameter of tank	⅙ times diameter of tank
Fixed Roof [See 2-2.1.4(a)]	Approved foam or inerting system	Diameter of tank	⅓ times diameter of tank
	Protection for Exposures*	2 times diameter of tank	⅔ times diameter of tank
	None	4 times diameter of tank but need not exceed 350 feet	⅔ times diameter of tank

SI Units: 1 ft = 0.3048 m.

*See definition for "Protection for Exposures."

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TABLE 2-4. UNSTABLE LIQUIDS

Type of Tank	Protection	Minimum Distance in Feet from Property Line Which Is or Can Be Built Upon, Including the Opposite Side of a Public Way	Minimum Distance in Feet from Nearest Side of Any Public Way or from Nearest Important Building on the Same Property
Horizontal and Vertical Tanks with Emergency Relief Venting to Permit Pressure Not in Excess of 2.5 psig	Tank protected with any one of the following: Approved water spray, Approved inerting, Approved insulation and refrigeration, Approved barricade	Table 2-6 but not less than 25 feet	Not less than 25 feet
	Protection for Exposures*	2½ times Table 2-6 but not less than 50 feet	Not less than 50 feet
	None	5 times Table 2-6 but not less than 100 feet	Not less than 100 feet
Horizontal and Vertical Tanks with Emergency Relief Venting to Permit Pressure Over 2.5 psig	Tank protected with any one of the following: Approved water spray, Approved inerting, Approved insulation and refrigeration, Approved barricade	2 times Table 2-6 but not less than 50 feet	Not less than 50 feet
	Protection for Exposures*	4 times Table 2-6 but not less than 100 feet	Not less than 100 feet
	None	8 times Table 2-6 but not less than 150 feet	Not less than 150 feet

SI Units: 1 ft = 0.3048 m.

*See definition for "Protection for Exposures."

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TABLE 2-5. CLASS IIIB LIQUIDS

Capacity Gallons	Minimum Distance in Feet from Property Line Which Is or Can Be Built Upon, Including the Opposite Side of a Public Way	Minimum Distance in Feet from Nearest Side of Any Public Way or from Nearest Important Building on the Same Property
12,000 or less	5	5
12,001 to 30,000	10	5
30,001 to 50,000	10	10
50,001 to 100,000	15	10
100,001 or more	15	15

SI Units: 1 ft = 0.3048 m; 1 gal = 3.785 L.

TABLE 2-6. REFERENCE TABLE FOR USE IN TABLES 2-1 TO 2-4

Capacity Tank Gallons	Minimum Distance in Feet from Property Line Which Is or Can Be Built Upon, Including the Opposite Side of a Public Way	Minimum Distance in Feet from Nearest Side of Any Public Way or from Nearest Important Building on the Same Property
275 or less	5	5
276 to 750	10	5
751 to 12,000	15	5
12,001 to 30,000	20	5
30,001 to 50,000	30	10
50,001 to 100,000	50	15
100,001 to 500,000	80	25
500,001 to 1,000,000	100	35
1,000,001 to 2,000,000	135	45
2,000,001 to 3,000,000	165	55
3,000,001 or more	175	60

SI Units: 1 ft = 0.3048 m; 1 gal = 3.785 L.

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3.0 STANDARD METAL TANK DESIGN

Many tanks to be used for storage and treatment of hazardous wastes are likely to have been fabricated from metals using the standards for design developed by association or societies of industry groups, insurers, or engineers. The primary purpose of Chapter 3.0 of this manual is to present the standards used during the fabrication of the common metal tanks likely to be encountered by permit writers. Chapter 4.0 presents similar information for non-metallic tanks and an approach on how to develop permits for used metal tanks or non-specification metal tanks.

This chapter starts with a general section on the regulations and issues to be considered in permitting a tank. Some of the issues in preparing the basis for tank design by the process engineer for use by the tank design engineer are then discussed. It is also noted that the applicant is required to specify the standards or equivalent information used to design and fabricate the tank. The subsequent section 3.2 presents abstracts of the various codes or standards used to design metal tanks, which is then followed by details on tank materials, fabrication, corrosion allowance, tank wall stress, and tank openings.

If the hazardous waste facility is to use new standard metal tanks, then the permit writer does not need to use Chapter 4.0. But, if a used standard metal tank or a new or used non-standard metal tank is or will be used in a hazardous waste facility, then the permit writers would likely refer to both Chapters 3.0 and 4.0.

3.1 General

This section of the manual covers information specific to the design (or selection) of tanks for use in hazardous waste facilities; Chapter 2.0 covered information with a more general "systems" orientation which pertained less to the design of the tank and more to either the environment of the tank or information which did not fit well in Chapter 3.

Subjects covered in this section include:

- Regulations pertaining to tanks
- Basis for tank design
- Requirement that applicant specify tank standards or design basis.

3.1.1 Regulations

The applicable regulations for design, fabrication, installation, operation, and closure of tanks at hazardous waste facilities are contained primarily in 40 CFR 264.190 through 264.199 and 270.16. A regulatory analysis of tanks in outline format is presented as Appendix A. Each of the specific items required in the regulation have been listed with

(a) The reference to the specific regulatory section and
(b) The preferred item designation of the permit application outline as given in "A Guide for Preparing RCRA Permit Applications for Existing Storage Facilities".

3.1.2 Basis for Tank Design

In the design of a tank, the designer takes into account the factors covered in the following sections of the chapter. The principal and initial factors to be considered are

- The amount and certain properties of the material to be contained, principally
  - the specific gravity
  - vapor pressure
  - corrosion behavior
- Type of service, i.e., operating conditions for the tank, (e.g., access requirements), connections required, and operating temperature range.

The corrosion behavior of the liquid influences materials selctions, e.g., carbon steel, painted, coated or lined carbon steel, stainless steel, etc. The specific gravity of the liquid influences the hydrostatic pressure in the tank. The vapor pressure determines the selection of an open or closed tank, need for venting and/or vapor control. The operating temperature range defines needs for low-temperature ductility, (i.e., no cold weather brittleness), and connections and access determine the need for welded connections and access ports, supports, etc. Once these major factors are defined, the majority of tanks can be specified in terms of existing experience, a large amount of which has been assembled in various codes and standards. Some standards or codes are stated in terms of design procedures, e.g., a set of steps using values from various tabulations of data; other standards or codes are stated in terms of final specifications, e.g., a range of conditions are described and final specifications (e.g., tank wall thickness) is given.

Similarly, standards have been written for the procedures for fabrication and construction, inspection and testing of tanks. These existing standards, developed by concensus and experience over a period of time, usually deal with the welding of tanks. Such standards are only recently available for fiberglass-reinforced tanks.

The following sections of this chapter discuss each factor in tank design and give brief descriptions of many of the commonly used standards and codes.

The remainder of this section will address

- Properties of the waste
- Operating conditions
- Nozzles and fittings.

3.1.2.1 Properties of the Waste. Section 2.3 previously presented the factors used to classify wastes as hazardous including toxicity, reactivity, corrosivity, and ignitability. Although these factors are important in the selection and design of tanks, two other properties should also be considered:

- Density (or specific gravity)
- Vapor pressure at maximum anticipated storage temperature.

As indicated in Table 3-1, "Impact of Selected Properties of the Waste on Tank Design", these factors are used to determine if the tank should be enclosed, if the proper materials of construction have been selected, and to calculate the thickness of the tank.

3.1.2.2 Operating Conditions. The operating conditions that are important in designing a tank for hazardous waste storage include:

- Pressure
- Temperature
- Liquid level.

The shell of a tank should be adequate to withstand specified design pressure. This design pressure is a function of the working pressure of the tank. If the tank is open to the atmosphere, even if through a small tube, then the working pressure is dependent only on the height and density of the liquid in the tank. For example, if the liquid height is 20 feet and the density of the liquid is 62.4 pounds/cubic foot (the same as water), then the pressure at the bottom of the tank is

$$\frac{\text{20 feet x 62.4 pounds}}{\text{cubic foot}} = \begin{array}{c|c} \text{20 feet} & \dfrac{\text{62.4 pounds}}{\text{cubic foot}} \end{array} = \frac{\text{1249 pounds}}{\text{square foot}}$$

or, if pounds per square inch (psi) is desired,

$$\begin{array}{c|c} \dfrac{\text{20 feet} \quad \text{62.4 pounds}}{\text{cubic foot}} & \dfrac{\text{square feet}}{\text{144 square inches}} \end{array} = 8.77 \text{ psi.}$$

Alternatively, if the liquid to be stored in a tank open to the atmosphere were some mixture "A" with a specific gravity of 0.93, then the pressure in psi could be calculated as follows:

$$\text{Density of "A"} = 0.93 \times 62.4 \frac{\text{pounds}}{\text{cubic foot}} = \frac{\text{58.0 pounds}}{\text{cubic foot}}$$

$$\text{and pressure} = \begin{array}{c|c|c} \text{20 feet} & \dfrac{\text{58 pounds}}{\text{cubic foot}} & \dfrac{\text{square foot}}{\text{144 square inches}} \end{array} = 8.1 \text{ psi}$$

TABLE 3-1. IMPACT OF SELECTED PROPERTIES OF THE WASTE ON TANK DESIGN

Property of Waste	Impact on Tank Design
Reactivity	None on storage tank unless reactive to water or carbon dioxide in the air, in which case the tank should be enclosed.
Toxicity	Tank should generally be enclosed (unless toxic components are not volatile or components are of low volatility and are not toxic at low concentrations).
Corrosiveness	A material of construction for the tank must be selected that has a low corrosion rate,or an effective liner or coating material must be used that is compatible with the waste (and operating conditions).
Ignitability	Generally, steel must be used for the tank and the tank must be enclosed.
Density (or specific gravity)	Used in computations to calculate the minimum required thickness of the tank. (Note: Density is measured in mass per unit volume such as pounds per cubic feet or grams per cubic centimeter, while specific gravity is the ratio of the density of the waste to the density of water.)
Vapor pressure (at maximum storage temperature)	Unless negligible (less than about 25 mm Hg (0.5 psi) may be used in computations of the minimum required thickness of the tank. It should be used in such computations if it is possible in any way to close off the tank (by valves or accidential blockages) without providing pressure relief.

However, if the tank is to be enclosed, then the pressure at the top of the tank will become at least equal to the vapor pressure of the material in the tank. For example, if the material "B" could be expected to reach a maximum of 90 F due to sunlight and ambient temperature during the day and its vapor pressure at 90 F were 2 atmospheres (absolute), then the pressure at the top of the tank would be

2 atmospheres absolute less 1 atmosphere = 1 atmosphere gauge*

$$\text{and 1 atmosphere gauge} \times \frac{14.7\ \text{psi}}{\text{atmosphere}} = 14.7\ \text{psi gauge} = 14.7\ \text{psig}$$

In the above situation, if the density were 50 pounds/cubic foot and the liquid height were 30 feet, then the pressure at the bottom of the tank could be calculated as

$$14.7\ \text{psig} + \frac{30\ \text{feet}}{} \left| \frac{50\ \text{pounds}}{\text{cubic foot}} \right| \frac{\text{square feet}}{144\ \text{square inches}} =$$

14.7 = 10.4 = 25.1 psig.

It should be noted that under a variety of conditions the pressure of a closed tank may exceed the values calculated above. For example, the pressure would be higher if air were originally trapped above the liquid.

Strength of material is also a function of temperature, with the strength of materials declining as temperature increases. However, the effect of temperature need not be considered for metals unless it exceeds 300 F (in which case, the applicable codes should be referred to by the permit writer).* Some caution should also be applied to use of materials such as rubber, plastics, and fiberglass-reinforced polyester materials if the maximum temperature exceeds about 120 F.

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*Vapor pressures of liquids are measured starting at zero absolute pressure. However, tank design is based on the difference between atmospheric pressure and the pressure in the tank.

3.1.2.3 Sizes of Nozzles and Fittings. In some cases, the permit application may not present a sufficiently detailed tank diagram to allow a complete determination of all nozzles and fittings on a tank. Furthermore, nozzles to be used for filling and emptying the tank during normal operations would seldom create hazardous situations.

The size of any overflow outlet (a port or pipe) should be larger than any inlet. For example, waste may be pumped into a tank under some condition of pump pressure and flow rate determined by pump characteristics. Any overflow will occur without pump pressure. Therefore, the overflow outlet should be larger than the inlet because, at overflow conditions, the overflow rate must accommodate the pump rate, but at lower pressure. A similar situation exists for vent and other pressure relief nozzles which must be sufficiently large to handle the maximum flow anticipated; furthermore, such nozzles should be used only for the purpose of venting and pressure relief.

It is beyond the scope of this manual to present the complex fluid flow equations to actually verify the design of vent and overflow nozzles. The permit writer should assure himself that such nozzles were designed instead of "guessed".

In general, vent pipes must be no less than 1-1/4 inches inside diameter (see NFPA 30, section 2.24) and may vary with tank size up to 4 inches in diameter for gasoline tanks in the size range of 35,000 to 50,000 gallons (UL 1316). These noted sizes are not universally applicable since vent size is dependent on vapor pressure, heating conditions, pumping rates, and other factors.

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*The use of the value of 300 F here is a conservative judgment; the existing standards for tank design dealt with here do not include any recognition of service at elevated temperature; it is judged that tank steels would undergo negligible change of properties up to 300 F.

3.1.2.4 Summary Checklist on Tank Design Basis. A "Summary Checklist for Tank Design Basis" is presented as Table 3-2.

3.1.3 Applicant to Specify Tank Standards

The applicant must specify the specific standards used for the tank design and the date of the applicable standard. Much information about the general applicability of the tank for the storage of hazardous waste is disclosed through knowing the applicable tank standard or code.

Non-standard tanks (such as rectangular tanks) have not been disallowed from use in hazardous waste facilities but, in such cases the Regional Administrator must be presented sufficient information to support the conclusion that such a tank has been adequately designed. The only source of such information is the applicant. The permitting of non-standard tanks normally will require significant engineering analyses to verify that such tanks can safely be used in a hazardous waste facility.

3.2 New Metal Tanks

This section of the manual deals with the standards and codes used for the fabrication of new standard metal tanks most likely to be encountered in hazardous storage and treatment facilities.

Specific subjects covered include:

- Standard codes
- Tank materials
- Tank fabrication and erection
- Tank wall corrosion allowance
- Tank wall stress
- Minimum thickness, corrosion allowance, and service life
- Tank openings
- Tank diagrams and data sheets.

The most common metal tanks likely to be used in hazardous waste facilities are those fabricated according to API Standard 620 for up to

TABLE 3-2. SUMMARY CHECKLIST FOR TANK DESIGN BASIS

Note: The answer to all questions should be "yes" or "not applicable".

1. If the waste is toxic or ignitable, is the tank enclosed? ________
2. If the waste is reactive to water or carbon dioxide (from the air), is the tank enclosed or under cover? ________
3. Has the tank been enclosed or covered if rain might overfill the tank? ________
4. Have materials of construction been carefully selected considering corrosivity and compatibility of the waste? ________
5. If the waste is ignitable, is the tank shell constructed of steel? ________
6. Has liquid height and its density been used in calculating the shell thickness? ________
7. If the tank is enclosed, has the vapor pressure of the waste been considered in calculating shell thickness? ________
8. If the tank is steel and the maximum operating temperature is greater than 260 F, has this been considered in calculating shell thickness? ________
9. If the tank or its liner or coating is rubber, plastic, fiberglass-reinforced plastic, or a paint, and the maximum operating temperature is greater than 120 F, has this been carefully evaluated as being safe? ________
10. Is the general capacity of the tank adequate to handle operational delays? ________
11. Is it likely that overfill and vent or pressure relief nozzles have been designed sufficiently large to perform their function? ________
12. Is there significant potential liquid height (several feet) above overfill nozzles to avoid undesirable spills? ________

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15 psig, API Standard 650 for up to 2.5 psig, UL Standard 142 for aboveground storage of flammable materials up to 0.5 psig, and UL Standard 58 for underground storage of flammable materials. Tanks fabricated in accordance with ASME Section VIII Division I and Division II for pressure vessels operating greater than 15 psig may occasionally be used in hazardous waste facilities when in new condition, but are more likely to be derated after having been used in other applications for use in hazardous waste storage at low pressure (less than 15 psig). NFPA Code 30 for flammable and and combustible liquids is not really a tank design standard, but covers other aspects of storage for such materials. Other codes and standards which are described briefly but would seldom be applicable to hazardous waste facilities include API Standard 12B for bolted production tanks, API Standard 12D for large production tanks, API Standard 12F for small oil-field serivce, API Standard 12A for tanks with riveted shells, and API Standard 1396.1 for welded aluminum-alloy storage tanks.

3.2.1 Standard Codes

Steel tanks intended for use in the petroleum or chemical processing industries are ordinarily specified to meet certain codes or standards, such as codes or standards which have been developed by the American Petroleum Institute (API), the American Society of Mechanical Engineers (ASME), the National Fire Protection Association (NFPA), or the Underwriters Laboratories (UL). Brief descriptions of standards most frequently encountered are given below.

3.2.1.1 API Standard 620

Title: "Recommended Rules for Design and Construction of Large, Welded, Low-Pressure Storage Tanks"

Scope: Rules cover design and construction of large, welded, low-pressure, carbon steel, aboveground tanks which have a single vertical axis of revolution and are to be operated at metal temperatures of 200 F or less and pressures in their gas or vapor spaces greater than permitted by API Standard 650 but not exceeding 15 psig. The rules provide for installations in areas where the lowest recorded one-day mean temperature is as low as -50 F. Some low alloy steels are also covered in the API 620 appendices.

3.2.1.2 API Standard 650

Title: "Welded Steel Tanks for Oil Storage"

Scope: This standard covers material, design, fabrication, erection, and testing requirements for vertical cylindrical, aboveground, closed and open top, welded steel storage tanks in various sizes and capacities for internal pressures near atmospheric pressure up to 2.5 psig. For tanks with open tops, floating roofs, or with bolted door sheets, metal operating temperatures shall not exceed 200 F; for certain shell materials and design features, metal operating temperatures may range up to 500 F. The standard covers only non-refrigerated service.

3.2.1.3 NFPA 30-1981

Title: "Flammable and Combustible Liquids Code" - 1977

Scope: The code applies to all flammable and combustible liquids except those that are solid at 100 F or above. The code contains separate chapters on tank storage; piping, valves, and fittings; container and portable tank storage; industrial plants; bulk plants; service stations; processing plants; and refineries, chemical plants, and distilleries. Rules for storage tanks concern aspects of tank materials, linings, fabrication, design standards, installation, site requirements, venting, and control of spillage.

Note that NFPA 30 is not a design standard for tanks, but prescribes which design standards may be used, and provides certain requirements or recommendations on the aspects noted above.

3.2.1.4 API 12B

Title: "API Specification for Bolted Production Tanks"

Scope: Specification covers material, design, and erection requirements for vertical cylindrical, aboveground, bolted-steel, production tanks in nominal capacities of 100 to 10,000 bbl for oil-field service. It also includes appurtenance requirements. Operating pressures will be near atmospheric pressure.

3.2.1.5 API 12D

Title: "API Specification for Large Welded Production Tanks"

Scope: Specification covers material, design, fabrication, and erection requirements for vertical cylindrical, aboveground, welded-steel, production tanks in nominal capacities of 500 to 3000 bbls for oil-field service. Operating pressures will be near atmospheric pressure.

3.2.1.6 API 12F

Title: "API Specification for Small Welded Production Tanks"

Scope: Specification covers material, design, and construction requirements for vertical cylindrical, aboveground, shop-welded steel production tanks in nominal capacities of 90 to 500 bbls for oil-field service. Operating pressures will be near atmospheric pressure.

3.2.1.7 API 12A

Title: "API Specification for Oil Storage Tanks with Riveted Shells"

Scope: API 12A tanks are flat-bottomed, vertical cylindrical tanks designed to operate at atmospheric pressure. The specification includes design specifications for materials; shell, roof, and bottom; fabrication and erection. Materials are ASTM A7 and A10 open hearth steel only. The designs include standard sizes from 240 to 255,000 bbl.

The 12A specification is not listed in the 1983 API Publications Catalog; a copy recently obtained from API was marked "historical" and was issued in 1951. Because riveted tanks are not expected to be commonly encountered, no further information is presented here.

3.2.1.8 ANSI Standard B96.1

Title: "American National Standard for Welded Aluminum-Alloy Storage Tanks"

Scope: This standard covers the design, fabrication, erection, inspection, testing of welded aluminum-alloy, field-erected or shop-assembled, above-ground, vertical cylindrical, flat-bottomed, atmospheric storage tanks of open- and closed-top construction. The design temperature covers the range from -20 F through +400 F. Typical nominal sizes range from 168 bbl to very large capacities.

Aluminum storage tanks will normally not be used because of their higher cost and poor corrosion resistance in many applications. Therefore, no further information is presented here.

3.2.1.9 UL 142

Title: "Steel Aboveground Tanks for Flammable and Combustible Liquids"

Scope: UL 142 requirements cover horizontal and vertical welded Steel tanks intended for the storage aboveground of flammable and combustible liquids at pressures between atmospheric and 0.5 psig. They are intended for use with only non-corrosive, stable liquids that have a specific gravity not exceeding that of water. Tanks covered by these requirements are fabricated, inspected, and tested for leaks before being shipped from the factory as completely assembled vessels. They are intended to meet the requirements of NFPA 30. Tanks shall be constructed of commercial or structural grade carbon steel or of Type 304 or 316 stainless steel, per specifications.

UL Standard 142 tanks are specified with little or no corrosion allowance, but such an allowance may be added. In general, the standard provides specifications and not a design procedure.

If inspection of a UL 142 tank results in the finding of significant corrosion, then the tank should be repaired or taken out of service unless a corrosion allowance was provided when the tank was fabricated.

The standard has been included for reference; no further discussion is presented here.

UL 142 contains no specifications, recommendations, or comments regarding the number, detailed design, or placement of supports for either horizontal or vertical tanks built according to this standard.

3.2.1.10 UL 58

Title: "Steel Underground Tanks for Flammable and Combustible Liquids"

Scope: UL 58 requirements cover horizontal cylindrical, atmospheric-type, welded steel tanks, intended for installation and use in accordance with NFPA No. 30, the Flammable and Combustible Liquids Code, and NFPA No. 31, Standard for the Installation of Oil-Burning Equipment. These tanks are fabricated, inspected, and tested for leaks before shipment from the factory. Capacities, dimensions, and metal thicknesses are specified in tables in the Standard. The steel shall be new, commercial quality, uncoated or galvanized, and of good welding quality.

In many respects, UL Standard 58 is similar to UL Standard 142; i.e., it presents specifications for the tanks and is not a design procedure. The Standard is not explicit regarding corrosive service; therefore, it is presumed that specified plate thicknesses include no corrosion allowance.

Manholes are permissible on the tanks; therefore, 40 CFR 264.190(b) may, or may not, be applicable, which states "The regulations of this Subpart [Subpart J—Tanks] do not apply to facilities that treat or store hazardous wastes in covered underground tanks that cannot be entered for inspection." Although the standard has been included for reference, no further discussion is presented here.

If inspection of a UL 58 tank results in the finding of significant corrosion, then the tank should be repaired or taken out of service unless a corrosion allowance was added when fabricated.

3.6.1.11 ASME Section VIII Division I

Title: "Rules for Construction of Pressure Vessels"

Scope: The rules in this Division of Section VIII cover minimum construction requirements for the design, fabrication, inspection and certification of pressure vessels other than those covered in other Sections and other exceptions. Subsection A covers the general requirements applicable to all pressure vessels. Subsection B covers the specific requirements that are applicable to the various methods of fabrication: welding, riveting, forging, and brazing. Subsection C covers specific requirements applicable to several classes of materials: carbon and low-alloy steels, non-ferrous metals, high-alloy steels, cast iron, clad and lined materials, cast nodular iron, and ferritic steels. The rules have been formulated on the basis of design principles and construction practices applicable to vessels designed for pressures up to 3000 psi. For pressures above 3000 psi, deviations from and additions to these rules are necessary to meet the requirements of design principles and construction practices for these higher pressures. The design temperature shall not be less than the mean metal temperature (through the thickness) expected under operating conditions; in no case shall the surface temperature exceed the maximum temperature listed in the stress tables for materials nor exceed temperature limitations specified elsewhere in Division I of Section VIII.

Corrosion service is covered by ASME Section VIII, Division I, Appendix E, "Suggested Good Practice Regarding Corrosion Allowance", and by ASME Appendix F, "Suggested Good Practice Regarding Linings". In the former, paragraph UA-156 states that "when the rate of corrosion is already predictable, additional wall thickness . . . shall be provided, which shall be at least equal to the expected corrosion loss during the desired life of the vessel". Paragraph UA-157 states that when the corrosion effects are indeterminate prior to design of the vessel, or when corrosion is incidental, localized, and/or variable in rate and extent, the designer must exercise his best judgment in establishing a reasonable maximum excess shell thickness. Paragraph UA-159 suggests that, when a vessel goes into corrosive service without previous service experience, service inspections be made at frequent intervals until the nature and rate of corrosion in service can be definitely established.

3.2.1.12 ASME Section VIII Division 2

Title: "Alternative Rules for Construction of Pressure Vessels"

Scope: The scope of Division 2 is similar to that of Division 1 as far as design pressures, design temperatures, etc., are concerned. The rules of Division 2 are more restrictive in the choice of materials which may be used, more precise design procedures are required, some common design details are prohibited, permissible fabrication procedures are specifically delineated and more complete examination, testing, and inspection are required.

3.2.2 Tank Materials

Each code or design standard has specific materials requirements either explicitly or by reference to material standards such as ASTM.

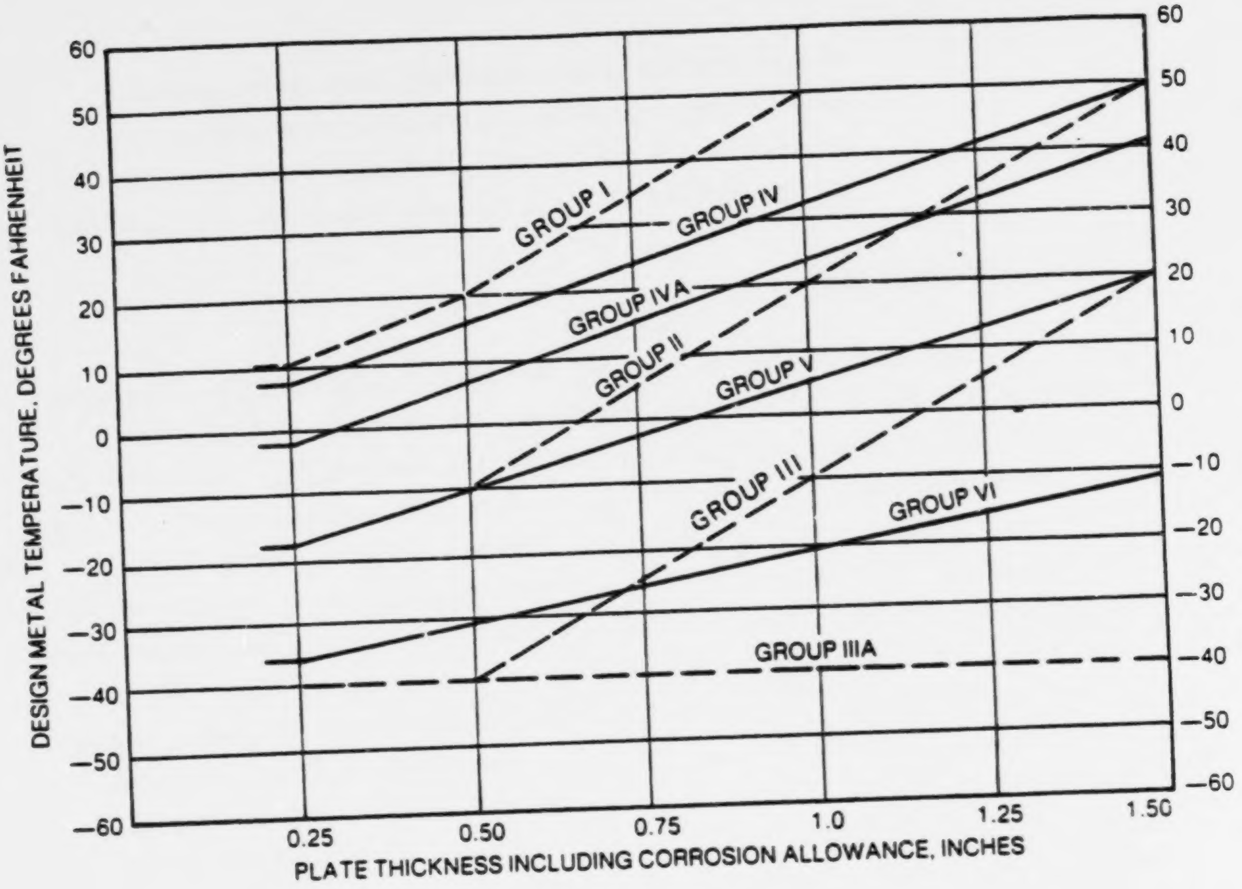
API Standard 650 deals with materials requirements in Section 2. These requirements are enunciated separately for plates, sheets, structural shapes, piping and forgings, flanges, bolting, and welding electrodes. A most important aspect of the requirements is the concept of design metal temperature. In API 650 the steel plates used for the shell of a tank must meet certain minimum values of toughness as exhibited by specified procedures (Charpy V-notch tests) depending on the lowest one-day mean temperature at the site of the tank. These temperatures are shown in Figure 2-1 of the API 650 for the whole United States. The permissible design metal temperatures are shown in Figure 3-1 for all of the groups of candidate steels (defined in Table 3-3). As an example, Figure 3-1 shows that, in a place where the design metal temperature is -30 F, plates as thick as 0.50 inch could be selected from Group VI; Group VI includes eight different ASTM specifications. See Section 2 of API 650 for details of specifications referred to above.

The API 620 materials specifications are qualitatively similar to those of API 650, just described. For details see Section 2 of API 620.

NFPA Code 30, "Flammable and Combustible Liquids Code", generally requires that tanks storing flammable or combustible liquids be fabricated of steel, but provides several exceptions and limitations as follow:

(a) The material of construction used for tank fabrication must be compatible with the flammable or combustible liquid.

(b) If the tank is constructed of a combustible material, its use must be approved by the appropriate authority and is limited to one of the following uses:



Notes:

1. See Table 2-3 for materials in each group.
2. Figure 2-2 is not applicable to controlled-rolled plates (see 2.2.7.4).

FIGURE 3-1. MINIMUM PERMISSIBLE DESIGN METAL TEMPERATURE FOR PLATES USED IN TANK SHELLS WITHOUT IMPACT TESTING (IN DEGREE FAHRENHEIT)

API Standard 650, Welded Steel Tanks for Oil Storage, Seventh Edition, 1980. Reprinted by courtesy of the American Petroleum Institute".

TABLE 3-3. MATERIALS GROUPS (See Figure 3-1)

Group I As-rolled Semi-killed		Group II As-rolled Killed or semi-killed		Group III As-rolled Killed Fine Grain Practice		Group IIIA Normalized Killed Fine Grain Practice	
Material	Notes	Material	Notes	Material	Notes	Material	Notes
A 283 C		A 131 B		A 573-58		A 131 CS	
A 285 C		A 36	5	A 516-55		Group III Materials	8
A 131 A		A 442-55		A 516-60			
A 36	2	A 442-60		G 40.21-38 T			
Fe 42 B		G 40.21-38 W		Fe 42 D	7		
Gr. 37	3, 4	G 40.21-44 W		Gr. 41	4, 7		
Gr. 41	4	Fe 42 C					
		Gr. 41	4, 6				

Group IV As-rolled Killed Fine Grain Practice		Group IVA As-rolled Killed Fine Grain Practice		Group V Normalized Killed Fine Grain Practice		Group VI Normalized or Quenched and Tempered Killed Fine Grain Practice Reduced Carbon	
Material	Notes	Material	Notes	Material	Notes	Material	Notes
A 573-65		A 662 C		A 573-70		A 131 EH 36	
A 573-70		A 573-70 Mod	9	A 516-65		A 633 C	
A 516-65		G 40.21-44 T	9	A 516-70		A 633 D	
A 516-70		G 40.21-50 T	9	G 40.21-44 T		A 537 I	
A 662 B				G 40.21-50 T		A 537 II	
G 40.21-44 T						A 678 A	
G 40.21-50T						A 678 B	
Fe 44 B, C, D	7					A 737 B	
Fe 52 C, D	7						
Gr. 44	4, 7						

Notes:

1. All specification numbers refer to ASTM specifications except G 40.21 which is a Canadian Standards Association specification; Fe 42, Fe 44, and Fe 52 which are contained in ISO Recommendation R 630; and Gr. 37, Gr. 41, and Gr. 44 which refer to national standards.
2. Limited to 0.50 inch thickness unless manganese content modified per 2.2.2 in which case it is limited to 1 inch thickness.
3. Maximum thickness 0.50 inch.
4. Maximum thickness 0.75 inches when control rolled.
5. Manganese content modified per 2.2.2.
6. Must be killed.
7. Must be killed and fine grain practice.
8. Must be normalized.
9. Must have chemistry (heat) modified to carbon maximum of 0.20 and manganese maximum of 1.60 (see 2.2.6.4).

API Standard 650, Welded Steel Tank for Oil Storage, Seventh Edition, 1980, Reprinted by courtesy of the American Petroleum Institute.

    (1) underground installation
    (2) where required by the stored liquid's properties
    (3) above-ground storage of liquid with a flash point greater than 200 F with no potential for a spill or leak in the area from a liquid with a flash point less than 140 F
    (4) Storage of liquid with a flash point greater than 200 F inside a building with an approved automatic fire extinguishing system

(c) Concrete tanks may be used as follows:

    (1) Unlined, if the API gravity is 40 or heavier (51.4 pounds/cubic foot)
    (2) Lined, if the API gravity is less than 40 and the tank must have been designed using sound engineering practices.

3.2.3 Tank Fabrication and Erection

The topics of fabrication and erection in the design standards generally are concerned with workmanship; tolerable deviations of tank lines and dimensions from plumb, roundness, etc; deviations of curved surfaces from design shape; adequacy of bearing strength of foundation; methods of shaping of plates not to affect mechanical properties; qualification of welders and welding procedure; and related items. In addition, they cover inspection and testing.

The design standards have detailed, specific requirements for inspection of welds - visually, by radiography, by sectioning, by leak testing with vacuum, air pressure, or reverse water pressure; for repair of welds; and, finally, for hydrostatic testing of the tank shell, including concurrent inspection for leaks. If the tank is to be a closed tank, the roof must also be tested for leaks by application of internal gas pressure and use of soap film or similar detector.

For more specific and detailed information, see the appropriate sections of the standards, as follows:

Standard 650:	Fabrication	Section 4
	Erection	Section 5
	Methods of Inspecting Joints	Section 6
Standard 620:	Fabrication	Section 4
	Inspection and Testing	Section 5

3.2.4 Tank Wall Corrosion Allowance

If a tank wall will be exposed directly to a corrosive liquid, i.e., no liner or coating and, therefore, is expected to corrode over a period of time, then a corrosion allowance must be made in the total wall thickness. Thus, the total initial minimum wall thickness t can be considered to have two components:

t_c = the corrosion allowance

t_s = the thickness required to carry the stress caused by the pressure.

The total initial minimum thickness $t = t_c + t_s$. Methods and data required for estimating t_c and t_s are given in later sections (3.2.5.1 and 3.2.6.4).

3.2.5 Tank Wall Stress

The stress in the steel wall of a vertical cylindrical tank containing a liquid or a gas or vapor under pressure will be tensile in the horizintal (hoop) direction (due to liquid head and gas/vapor pressure) and generally, for low pressure tanks, will be compressive in the vertical direction (due to the weight of the wall itself, plus the weight of the roof resting on the wall). The compressive stress at the bottom of a uniform-thickness wall, due only to the weight of the steel wall itself, will be about 3.4 psi per foot of height.* This will usually be a small fraction of the tensile circumferential stress in the wall of a tank operating at its design pressure, especially for the small tanks used to store hazardous liquids.

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*Calculated on the basis of a density of steel of 0.28 pounds per cubic inch.

3.2.5.1 API 620 Tanks. As indicated in 3.2.1.1, API Standard 620 covers the design of tanks with a single vertical axis which may be operated at pressures in their gas or vapor spaces up to 15 psig. If a tank were to be designed for such a pressure, it is most probably that the tank would be designed with hemispherical or ellipsoidal or similar top and bottom; a flat bottom would not be practical because of anchoring required to prevent uplift and damage to the wall/bottom connection. If the operating gas space pressure were to be only, say, 3 psi, then in some circumstances a flat bottom might be practical. For the design of tanks with non-flat bottoms, see API Standard 620, Section 3.9.

API 620 prescribes "least permissible thicknesses" for the tank wall as the greatest of the following:

(1) 3/16 inch plus the corrosion allowance
(2) the calculated thickness per section 3.10.3 of API 620 plus the corrosion allowance
(3) the nominal thickness as per Table 3-4 of API 620:

Tank Radius (ft)	Nominal Plate Thickness (inch)
0-25 inclusive	3/16*
over 25-60 inclusive	1/4
over 60-100 inclusive	5/16
over 100	3/8

A tank to be designed according to API 620 and to be operated to, say, 15 psig in the gas/vapor space would have a bottom and a roof which are curved figures of revolution about a vertical axis. The design calculations for such a tank are complex and beyond the scope of this manual; the API Standard 620 should be consulted for a description of the design methods. It is assumed in what follows that a tank having a flat bottom has been designed according to API 620 for operation at the low end of the range 2.5 to 15 psig. (Such a tank might be similar to one designed according to API 650 except that the upper limit of design pressure in API 650 is 2.5 psig.)

---

*The Seventh Edition of API 620 (September 1982) shows the thickness as 3/18 inch. It is believed that this is a misprint. Clarification has been requested from API in Washington, D.C.

Some vertical cylindrical tanks have courses with different thicknesses, the bottom course being thickest and the top course being thinnest. Generally, the tensile circumferential stress at the bottom of any course in a vertical cylindrical tank is given by

$$S = \frac{P \times d}{2 \times t_s}$$

where P = total pressure at bottom edge of course
= liquid head + pressure in vapor space
= $HG + P_v$

and

P_v = pressure in vapor space
H = maximum height of liquid above bottom edge of a given course
G = density of liquid
S = maximum allowable stress for simple tension
d = diameter of tank
t_s = thickness of wall course required to carry the pressure = total thickness - corrosion allowance

(Equation 1 will give accurate values of hoop stress at all levels except in the bottom portion of the bottom course. In this region the hoop stress will be less than the value from Equation 1 due to the restraint given by the bottom of the tank. However, this restraint also produces bending stress in the wall.)

The design standard allows certain maximum stresses for specified grades of steel. The maximum stresses must be calculated by multiplying the "maximum allowable tensile stress for simple tension" for the specified grade of steel by the joint efficiency for the type of weld. The "maximum allowable tensile stress for simple tension" is presented in Table 3-1 in API Standard 620, in the right hand column. The joint efficiency varies by the type of joint and the completeness of radiographic examination and is

TABLE 3-4. MAXIMUM ALLOWABLE STRESS VALUES FOR SIMPLE TENSION

Specification No. (See Note 1)	Grade	Notes	Specified Minimum		Maximum Allowable Tensile Stress for Simple Tension, S_a (pounds per square inch) (See Note 2, 3)
			Tensile Strength (pounds per square inch)	Yield Point (pounds per square inch)	
Plates					
ASTM A 36	-	5	58,000	36,000	16,000
ASTM A 131	A	4, 5, 6	58,000	34,000	15,200
ASTM A 131	B	5	58,000	34,000	16,000
ASTM A 131	CS	5	58,000	34,000	16,000
ASTM A 283	C	4, 5	55,000	30,000	15,200
ASTM A 283	D	4, 5, 6	60,000	33,000	15,200
ASTM A 285	C	4	55,000	30,000	16,500
ASTM A 442	55	—	55,000	30,000	16,500
ASTM A 442	60	—	60,000	32,000	18,000
ASTM A 516	55	—	55,000	30,000	16,500
ASTM A 516	60	—	60,000	32,000	18,000
ASTM A 516	65	—	65,000	35,000	19,500
ASTM A 516	70	—	70,000	38,000	21,000
ASTM A 537	Class 1	8	70,000	50,000	21,000
ASTM A 537	Class 2	8	80,000	60,000	24,000
ASTM A 573	58	5	58,000	32,000	16,000
ASTM A 573	65	5	65,000	35,000	18,000
ASTM A 573	70	5	70,000	42,000	19,300
ASTM A 633	C and D	5, 8	70,000	50,000	19,300
ASTM A 662	B	—	65,000	40,000	19,500
ASTM A 662	C	8	70,000	43,000	21,000
ASTM A 678	A	5, 7	70,000	50,000	19,300
ASTM A 678	B	5, 8	80,000	60,000	22,100
ASTM A 737	B	8	70,000	50,000	21,000
CSA G 40.21	38W and 38T	5	60,000	38,000	16,500
CSA G 40.21	44W and 44T	5	65,000	44,000	18,000
ISO R630 Fe 42	C and D	5	60,000	34,000	16,500
ISO R630 Fe 44	C and D	5	62,500	35,500	17,300
ISO R 630 Fe 52	C and D	5	71,000	48,500	19,600
Pipe					
Seamless					
API Std 5L	B	—	60,000	35,000	18,000
ASTM A 53	B	—	60,000	35,000	18,000
ASTM A 106	B	—	60,000	35,000	18,000
ASTM A 106	C	—	70,000	40,000	21,000
ASTM A 333	O	—	55,000	30,000	16,500
ASTM A 333	3	—	65,000	35,000	19,500
ASTM A 524	I	—	60,000	35,000	18,000
ASTM A 524	II	—	55,000	30,000	16,500
Electric-Fusion-Welded					
ASTM A 134	A 283 Grade C	4, 5, 9	55,000	30,000	12,100
ASTM A 134	A 285 Grade C	4, 9	55,000	30,000	13,200
ASTM A 139	B	9	60,000	35,000	14,400
ASTM A 671	CA55	9	55,000	30,000	13,200
ASTM A 671	CC60	9	60,000	32,000	14,400
ASTM A 671	CC65	9	65,000	35,000	15,600
ASTM A 671	CC70	9	70,000	38,000	16,800
ASTM A 671	CD70	8,9	70,000	50,000	16,800
ASTM A 671	CD80	8,9	80,000	60,000	19,200
ASTM A 671	CE55	9	55,000	30,000	13,200
ASTM A 671	CE60	9	60,000	32,000	14,400

TABLE 3-4. MAXIMUM ALLOWABLE STRESS VALUES FOR SIMPLE TENSION (continued)

Specification No. (See Note 1)	Grade	Notes	Specified Minimum: Tensile Strength (pounds per square inch)	Specified Minimum: Yield Point (pounds per square inch)	Maximum Allowable Tensile Stress for Simple Tension, S_{ts} (pounds per square inch) (See Note 2, 3)
Forgings					
ASTM A 105	—	—	60,000	30,000	18,000
ASTM A 181	I	—	60,000	30,000	18,000
ASTM A 181	II	—	70,000	36,000	21,000
ASTM A 350	LF1	—	60,000	30,000	18,000
ASTM A 350	LF2	—	70,000	36,000	21,000
ASTM A 350	LF 3	—	70,000	40,000	21,000
Castings and Bolting					
ASTM A 27	60–30	10	60,000	30,000	14,400
ASTM A 193	B7	—	125,000	105,000	24,000
ASTM A 307	B for flanges and pressure parts	11	55,000	—	8,400
ASTM A 307	B for structural parts and anchor bolting	—	55,000	—	15,000
ASTM A 320	L7	—	125,000	105,000	24,000
Structural Shapes Resisting Internal Pressure					
ASTM A 36	—	5, 6	58,000	36,000	15,200
ASTM A 131	A	5, 6	58,000	34,000	15,200

NOTES:

1. All pertinent modifications and limitations of specifications required by 2.2 through 2.6 shall be complied with.

2. Except for those cases where additional factors or limitations are applied as indicated by references to Notes 5, 6, 10, or 11, the allowable tensile stress values given in this table for materials other than bolting steel are the lesser of: (a) 30 percent of the specified minimum ultimate tensile strength for the material, or (b), 60 percent of the specified minimum yield point.

3. Except where a joint efficiency factor is already reflected in the specified allowable stress value, as indicated by the references to Note 10, or where the value of *N* determined in accordance with 3.5.2.2 is less than the applicable joint efficiency given in Table 3–6 (and therefore effects a greater reduction in allowable stress than the pertinent joint efficiency factor would effect, if applied), the specified stress values for welds in tension shall be multiplied by the applicable joint efficiency factor, *E*, given in Table 3–6.

4. Plates and pipe shall not be used in thicknesses greater than ¾ inch.

5. Stress values for structural quality steels include a quality factor of 0.92.

6. Stress values are limited to those for a steel having an ultimate tensile strength of only 55,000 pounds per square inch.

7. To 1½ inch thickness, inclusive.

8. To 2½ inch thickness, inclusive.

9. Stress values for fusion-welded pipe include a welded-joint efficiency factor of 0.80. (See note in 3.23.2.) Only straight-seam pipe shall be used; the use of spiral-seam pipe is prohibited.

10. Stress values for castings include a quality factor of 0.80.

11. Allowable stress based on Section VIII of the 1980 ASME *Boiler and Pressure Vessel Code*, multiplied by the ratio of the design stress factors in API Standard 620 and ASME Section VIII, namely 0.30/0.25.

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presented in API Standard 620 as Table 3-6, "maximum allowable efficiencies for arc-welded joints". For example, if a tank is built with ASTM A36 steel plate and the joints are double-welded butt joints spot radiographed, then the maximum allowable tensile stress S_{ta}

$$S_{ta} = 16000 \text{ psi} \times 0.85 = 13600 \text{ psi}.$$

If the compressive (vertical) stresses are large (greater than 5 percent of the tensile circumferential stress), then the maximum allowable stress must be reduced further by a factor given in Figure 3-1 of API 620. However, for cases where the compressive stress does not exceed 5 percent of the tensile stress (likely for small hazardous liquid tanks), then the design may use the values as calculated in the example above.

Equation 1 can be arranged to yield t_s directly:

$$t_s = \frac{P \times d}{2 \times S} \qquad (2)$$

where the allowable value of stress is obtained from the standard itself, as explained above. In using Equation 2, consistent units must be used. For example, to obtain t_s in inches, express d and H in inches, P and S in bls/in^2 (psi), and G in lbs/in^3. Other units may be used if care is taken to convert to compatible units. Thus, if G is used in lbs/ft^3 and H and d in feet, the formula becomes:

$$t_s(\text{in}) = \frac{\left[\frac{H(\text{ft})\ G(\text{lb/ft}^3)}{144} + P_v(\text{psi})\right]\left[d(\text{ft}) \times 12\right]}{2 \times S\ (\text{psi})} \qquad (3)$$

If the tank is open, i.e., is vented to the atmosphere, then $P_v = 0$ and

$$t_s(\text{in}) = \frac{1}{24}\ \frac{H(\text{ft})\ G(\text{lb/ft}^3)\ d(\text{ft})}{S\ (\text{psi})} \qquad (4)$$

If all courses of a tank are the same thickness, then the above calculations (using Equation 3 or 4) must be made only once using H = maximum height of liquid above bottom of lower edge of first course.

TABLE 3-5. MAXIMUM ALLOWABLE EFFICIENCIES FOR ARC-WELDED JOINTS

Type of Joint	Limitation	Basic Joint Efficiency (Note 1) (percent)	Radio-graphed (Note 2)	Maximum Joint Efficiency (Note 3) (percent)
Double-welded butt joint	None	85	Spot Full (Note 4)	85 100
Single-welded butt joint with backing strip or equivalent	Longitudinal or meridional joints and circumferential or latitudinal joints between plates not over 1¼ inches thick, and nozzle attachment welding without thickness limitation.	75	Spot Full (Note 4)	75 85
Single-welded butt joint without backing strip	Nozzle attachment welding.	70	—	70
Double full-fillet lap joint	Longitudinal or meridional joints and equivalent (Note 5) circumferential or latitudinal joints between plates not over ⅜ inches thick, except that joints of this type shall not be used for longitudinal or meriodinal joints which the provisions of 3.12.1 require to be butt-welded.	70	—	70
	Other circumferential or latitudinal joints between plates not over ⅜ inches thick.	65	—	65
Single full-fillet lap joint	Longitudinal or meridional joints and circumferential or latitudinal joints between plates not over ⅜ inches thick, except that joints of this type shall not be used for longitudinal or meridional joints which the provisions of 3.12.1 require to be butt-welded. Multipass welding is required when the thinner plate joined exceeds ¼ inch.	35	—	35
Single full fillet lap joints for head to nozzle joints	For the attachment of heads convex to pressure not over ⅝ inch required thickness, only with use of fillet weld on inside of nozzle.	35	—	35
Nozzle attachment fillet welds	Attachment welding for nozzles and their reinforcements.	[Included in strength factors in 3.16.7.2 Item 1]		
Plug welds (see 3.24.5)	Attachment welding for nozzle reinforcements. (Note 6)	80	—	80

NOTES:

1. Spot examination in all main seams as specified in 5.16 when not completely radiographed.
2. See 3.26 and 5.15.
3. Regardless of any values given in this column, the efficiency for lap-welded joints between plates having surfaces of double curvature, which have a compressive stress across the joint from a negative value of P_G or other external loading, may be taken as unity; but such compressive stress shall not exceed 700 pounds per square inch. For all other lap-welded joints, the joint efficiency factor must be applied to the allowable compressive stress, S_{ca}. The efficiency for full-penetration butt-welded joints, which are in compression across the entire thickness of the connected plates, may be taken as unity.
4. All main butt-welded seams completely radiographed as specified in 5.15, and nozzle and reinforcement attachment welding examined by magnetic-particle method as specified in 5.20.
5. For the purposes of this table, a circumferential or latitudinal joint shall be considered to be subject to the same requirements and limitations as longitudinal or meridional joints when such circumferential or latitudinal joint is located: (a) in a spherical, torispherical, or ellipsoidal shape or in any other surface of double curvature; (b), at the junction between a conical or dished roof (or bottom) and cylindrical sidewalls, such as considered in 3.12.2; or (c), at a similar juncture at either end of a transition section or reducer such as shown in Figure 3-7.
6. The efficiency factors shown for fillet welds and plug welds are not to be applied to the allowable shearing stress values shown in Table 3-2 for structural welds.

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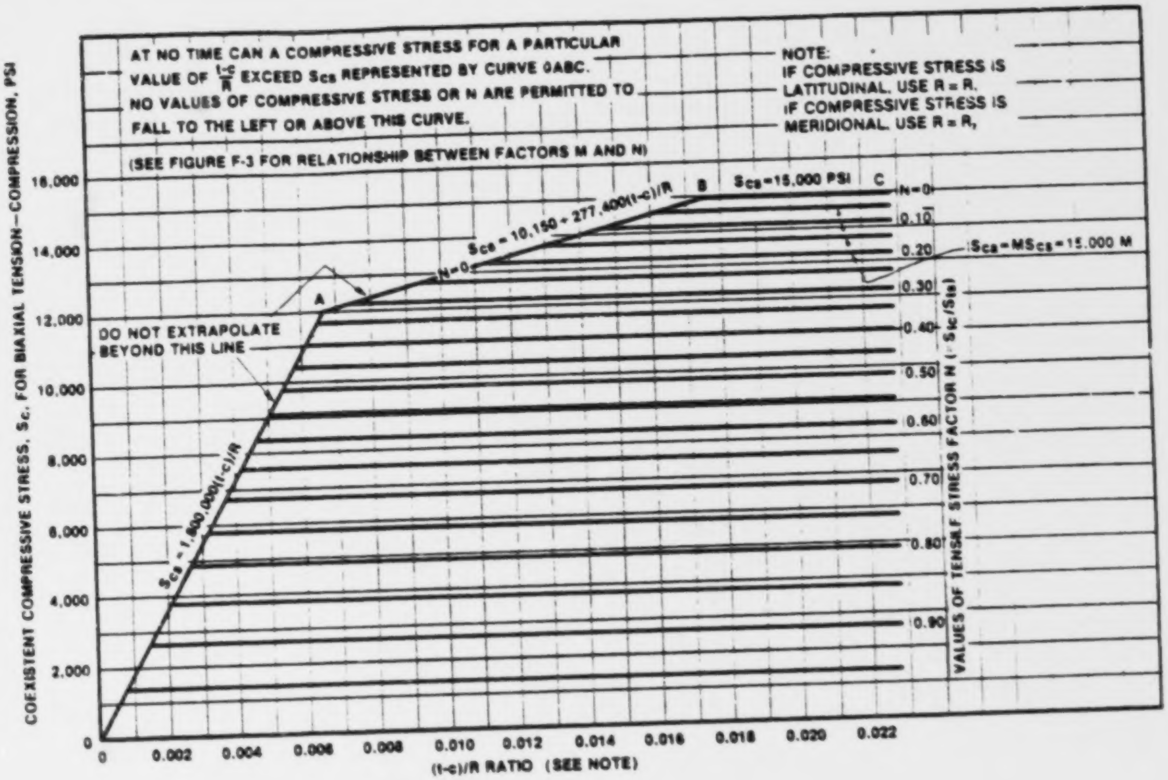

FIGURE 3-2. BIAXIAL STRESS CHART FOR COMBINED TENSION AND COMPRESSION, 30,000 TO 38,000 PSI YIELD STRENGTH STEELS

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If the calculated (required) total thickness of any course ($t = t_c + t_s$) is greater than the actual thickness of that course, then a possible mode of operation would be to reduce the allowable maximum height of liquid to a value where the calculated thickness is less than the actual thickness. In this case, Equation 3 can be rearranged to yield H directly:

$$H\ (\text{ft}) = \frac{144}{G(\text{lb/ft3})}\left[\frac{S(\text{psi})\ t_s(\text{in})}{6\ d(\text{ft})} - P_v(\text{psi})\right]$$

If this equation is applied to each of several courses of a tank, then the allowable H would be the smallest value found among the results.

3.2.5.1.1 Sample Calculation. Assume a tank is to be designed to API 620 for a liquid with the following properties:

- Vapor pressure at 100 F = 10 psig
- Density = 80 lb/ft3

Tank to be built of A36 steel, single-welded butt joints with spot radiographs, 30 feet high and 20 feet diameter; maximum liquid height = 28 feet; maximum steel temperature, 100 F.

These design values give:

P_v = 10 psig
S = 16000 x 0.75 = 12000 (tensile strength [from Table 3-4] x weld efficiency factor [from Table 3-5])
d = 20 feet
H = 28 feet
G = 80 bl/ft3.

Assuming that the compressive stress in the bottom course is less than 5 percent of 12000 psi, Equation 3 then will give t_s for the bottom course as follows:

$$t_s = \frac{\left[\frac{28 \times 80}{144} + 10\right]\left[20 \times 12\right]}{2 \times 12000}\ \text{inch}$$

$$= \frac{[15.6 + 10]\ [240]\ \text{inch}}{24000}$$

$$= 0.26\ \text{inch.}$$

3.2.5.2 API 650 Tanks. Shell design in the 650 Standard can be considered to begin with a choice of plate material from a list of permissible materials in Table 3-2 of the Standard (see Table 3-6). This table presents a number of ASTM, CSA, National Standard, and ISO-R630 Standards specifications and grades of steel plate which are permissible. Also shown are minimum yield and tensile strengths, product design stress S_d, and hydrostatic test stress St. It is noted that for some steel specifications/grades, Table 3-2 (of the Standard) shows lower values of S_d or S_t for the first (bottom) course than for upper courses.

Since the applicant is required to report the design standard used and do the deisgn calculations, the permit writer must merely review the submitted information. A brief discussion of methods which may be referenced by the applicant is given below.

Section 3.6 of the 650 Standard cites two methods of calculating shell thickness:

- One-Foot Method
- Variable Design Point Method.

The Variable Design Point Method normally provides a reduction in shell course thicknesses and total material weight than will be obtained by the One-Foot Method. As cited in Section 3.6 of API 650, a more important aspect of this procedure is its potential to permit construction of larger diameter tanks within the maximum plate thickness limitation (i.e., without impact testing). The method is illustrated by an example in Appendix K of Standard 650. Since tanks for storage of hazardous fluids are expected to be relatively very small (in the range of tens of thousands of gallons), the major advantage of the Variable Design Point Method will not be realized for them.

The One-Foot Method may be used, and most likely in the simplified form of Appendix A of Standard 650, which provides an optional design basis for relatively small tanks. These tanks would be field-erected tanks in which the stressed components are limited to a maximum of 1/2 inch nominal thickness, including any corrosion allowance; the maximum design tensile stress is 21,000 psi. Such tanks also are limited to design metal

TABLE 3-6. PERMISSIBLE PLATE MATERIALS AND ALLOWABLE STRESSES (in pounds per square inch)

Plate Specification	Grade	Minimum Yield Strength	Minimum Tensile Strength	Product Design Stress S_d		Hydrostatic Test Stress S_t	
				1st Course	Upper Course	1st Course	Upper Course
ASTM							
A283	C	30,000	55,000	20,000	20,000	22,000	22,500
A285	C	30,000	55,000	20,000	20,000	22,000	22,500
A131	A,B,CS	34,000	58,000	21,800	22,700	23,200	24,900
A131	EH 36	51,000	71,000[1]	26,600	28,400	28,400	30,400
A36		36,000	58,000	21,800	23,200	23,200	24,900
A442	55	30,000	55,000	20,000	20,000	22,000	22,500
A442	60	32,000	60,000	21,300	21,300	24,000	24,000
A573	58	32,000	58,000	21,300	21,300	23,200	24,000
A573	65	35,000	65,000	23,300	23,300	26,000	26,300
A573	70	42,000	70,000[1]	26,300	28,000	28,000	30,000
A516	55	30,000	55,000	20,000	20,000	22,000	22,500
A516	60	32,000	60,000	21,300	21,300	24,000	24,000
A516	65	35,000	65,000	23,300	23,300	26,000	26,300
A516	70	38,000	70,000	25,300	25,300	28,000	28,500
A662	B	40,000	65,000	24,400	26,000	26,000	27,900
A662	C	43,000	70,000[1]	26,300	28,000	28,000	30,000
A537	1	50,000	70,000[1]	26,300	28,000	28,000	30,000
A537	2	60,000	80,000[1]	30,000	32,000	32,000	34,300
A633	C,D	50,000	70,000[1]	26,300	28,000	28,000	30,000
A678	A	50,000	70,000[1]	26,300	28,000	28,000	30,000
A678	B	60,000	80,000[1]	30,000	32,000	32,000	34,300
A737	B	50,000	70,000[1]	26,300	28,000	28,000	30,000
CSA Standards							
G40.21	38	38,000	60,000	22,500	24,000	24,000	25,700
G40.21	44	44,000	65,000	24,400	26,000	26,000	27,900
G40.21	50	50,000	70,000[1]	26,300	28,000	28,000	30,000
National Standards							
	37	30,000	52,600	19,700	20,000	21,000	22,500
	41	34,000	58,300	21,900	22,700	23,300	25,000
	44	36,000	62,600	23,500	24,000	25,000	26,800
ISO-R630 Standards							
Fe 42	B,C	34,000	60,000	22,500	22,700	24,000	25,500
Fe 44	B,C	35,500	62,500	23,400	23,700	25,000	26,600
Fe 52	C,D	48,500	71,000[1]	26,600	28,400	28,400	30,400

Note:

1. By agreement between purchaser and manufacturer, the tensile strength of these materials may be increased up to 75,000 psi minimum and 90,000 psi maximum (and to 85,000 psi minimum and 100,000 psi maximum for ASTM A 537, Class 2 and A678, grade B). When this is done the allowable stresses shall be determined as stated in Par. 3.6.2.1 and 3.6.2.2.

API Standard 650, Welded Steel Tanks for Oil Storage, Seventh Edition, 1980.
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tures above minus 20 F (above minus 40 F when killed and fine grain material is used). For a more complete description of the design methods, materials, and limitations, see Appendix A of API Standard 650.

In the One-Foot Method of calculating shell plate thicknesses, the required minimum thickness shall be the greater of the values computed from the following formulae:

$$\text{Design shell thickness } t_d^{(in)} = \frac{2.6\ d(H-1)g}{S_d} + \text{C.A.}$$

$$\text{Hydrostatic test shell thickness } t_t^{(in)} = \frac{2.6\ d(H-1)}{S_t}$$

where

d = nominal diameter of tank, feet

H = height from bottom of course to maximum height of liquid, feet

g = specific gravity of liquid

C.A. = corrosion allowance, inch

S_d = allowable design stress, psi

S_t = allowable stress for hydrostatic test condition

The Standard also specifies that the total shell thickness for each course shall not be less than required by Sections 3.6.1.1, 3.6.1.6, and 3.6.1.7 of Standard 650. These requirements are:

API 650, Section 3.6.1.1

(1) Design shell thicknesses, including corrosion allowance, or

(2) Hydrostatic test shell thicknesses (excluding corrosion allowance)

(3) But in no case shall the shell thickness be less than the following:

Nominal Tank Diameter[1] (feet)	Nominal Plate Thickness[2] (inches)
Smaller than 50	3/16
50 to 120, exclusive	1/4
120 to 200, inclusive	5/16
Over 200	3/8

Notes: 1. Nominal tank diameter shall be centerline diameter of the bottom shell course plates, unless otherwise specified by the purchaser.

2. Nominal plate thickness refers to the tank shell as constructed. The thicknesses specified are based on erection requirements.

The minimum thicknesses specified by (3) apply to all tanks.

API 650, Section 3.6.1.6

The calculated stress for each course shall not be greater than permitted for the particular material for that course. No shell course shall be thinner than the course above it. The design stress for an upper shell course shall not be greater than the design stress for a lower shell course.

API 650, Section 3.6.1.7

The tank shell shall be checked for stability against buckling from the design wind velocity by the rules of Section 3.9.7 of API 650. If required, additional structural members or increased plate thicknesses, or both, shall be utilized.

Minimum thicknesses are also specified for bottom plates. All bottom plates shall have a minimum (nominal) thickness of 1/4 inch (6.0 mm) when specified by the purchaser. Annular bottom plates shall have (nominal) thicknesses not less than those listed in Table 3-1 of the Standard. No further calculations are required. (All thicknesses specified in design standards are nominal, and material is purchased by the manufacturer by nominal thickness. Dimensional tolerances on the plate thicknesses are given in the material specification, e.g., ASTM.)

3.2.5.3 UL 58 and 142 Tanks. UL 142 steel above-ground tanks are explicitly stated as being intended only for use with non-corrosive, stable liquids. Based on an analysis of the testing procedure used for UL 58 steel underground tanks, it is clear that such tanks are also intended only for use with non-corrosive liquids. Thus, it is concluded that the entire original shell thickness is required for the anticipated tank wall stresses likely to be imposed and there is no inherent corrosion allowance in these standards. However, corrosion allowance may be added to the thicknesses.

3.2.5.4 ASME Section VIII Pressure Vessels. In uncommon situations where tanks for pressures greater than 15 psig are required in hazardous waste facilities, then the ASME rules for Section VII pressure vessels will be required as guidance. Corrosion allowances are used in such vessels. (See Section 3.2.1.11 of this manual for more information.) If used pressure vessels are to be derated for use in atmospheric or low pressure hazardous waste storage, then API 650 or API 620 can be used for guidance in setting the minimum shell thickness. The minimum thickness for the tops and bottoms are more difficult to specify because the "special heads" typically used for pressure vessels are capable of withstanding greater pressure at equal thickness than the flat bottoms and tops used in API 620 and 650 tanks. The applicant should provide the engineering information to support a suggested minimum top and bottom thickness in the permit application for each such tank. In some cases, API Standard 620 may provide adequate guidance for tops and bottoms.

3.2.6 Minimum Thickness, Corrosion Allowance, and Service Life

The following section considers wall thickness and corrosion allowance as they interact with the expected service life of a tank.

3.2.6.1 Minimum Shell Thickness. Title 40 CFR 264.191(a) states that "Tanks must have sufficient shell strength . . to assure that they do not collapse or rupture . . . The Regional Administrator shall require that a minimum shell thickness be maintained at all times to ensure sufficient shell strength." The design standards presented in sections 3.2.1 and the tank wall stress considerations discussed in section 3.2.5 of this manual either provide the procedure to compute the minimum shell thickness required by 40 CFR 264.191(a) or specify such a wall thickness. Such a computed or specified minimum thickness includes a negligible allowance for minor surface corrosion and some allowance for unexpected stresses owing to pressure changes. On the basis of applicable design standards or other engineering information, the permit writer will specify a minimum thickness for the tank in the facility's permit. The owner or operator is expected to maintain this minimum thickness throughout the service life of the tank.

The consideration of non-uniform thickness in a corroded tank is illustrated in a following section (see Example 3 in section 3.2.6.4 of this report.)

3.2.6.2 Corrosion Allowance. Corrosion allowance is defined as the difference between the actual thickness of a tank's walls at a given time and the required minimum thickness of the tank wall. (Measures of wall thickness should be exclusive of the thickness of any linings or coatings applied to the tank walls. However, use of coatings or lining to protect and maintain wall thickness is encouraged in many cases.) Because corrosion is a continuous process, the corrosion allowance diminishes over time.

3.2.6.3 Expected Service Life. Expected service life is defined as the corrosion allowance divided by the corrosion rate of the waste upon the construction materials of the tank. The expected life is the amount of time that a hazardous waste can be stored in a tank before the corrosive action of the waste causes the thickness of the tank walls to equal the minimum required thickness. Information on the expected service life is valuable in determining frequency of inspection and renewal dates for permits. The National Association of Corrosion Engineers (NACE) and others have published data on corrosion rates for different relatively pure chemicals. Representative tables and a discussion of their use are contained in the permit writers' guide on hazardous waste compatibility. These tables can be used to estimate the corrosion rates of such chemicals if the chemicals stored have similar properties. Further information about corrosion rates is presented in Appendix B of this manual.

Caution should be exercised in relying upon published corrosion rates since such factors as the oxygen and water content and the chloride content of the waste can significantly affect the corrosion rate, causing substantial variation from the published value.

Unfortunately, hazardous wastes are usually mixtures of chemicals; the corrosion rates of materials exposed to them are likely not to be known. In such circumstances where the corrosion rate of the mixture is not known, a conservative approach is recommended. In general, the corrosion rate is not profoundly affected by the concentration of salts in aqueous solutions; that is, if the concentration is reduced by 50 percent, the corrosion rate may not be reduced at all or far less than 50 percent.

A procedure for estimating the corrosion rate of mixtures would be first to determine the chemicals and the range of their concentrations in the mixture. Then, through the NACE (or other) data, determine the corrosion rate (at the indicated concentration range if possible) for each of the chemicals present with the material of construction of the tank interior. After this data has been tabulated, the highest corrosion rate indicated should be selected as the anticipated corrosion rate of the tank with the mixture. Based on this value, the anticipated service life for the tank may be calculated, from which the required inspection frequency can be specified by the permit writer partially contingent on results of future periodic inspections. The desirability of acquiring corrosion test data before the first tank inspection by exposing (within the tank) test specimens of the specific material of construction used for the tank to the hazardous waste mixuture may become obvious. (See Section 8.6.2.2 of this manual for further information.)

In order to estimate the expected service life of a tank, the permit writer should determine:

- The standard code used for building the tank and its date or edition
- The specific materials of construction and their properties
- The required minimum thickness of the shell plates of a tank (a function of the contained liquid's specific gravity, height of liquid level, and diameter of the tank)
- The corrosion allowance
- The presumed initial corrosion rate or the actual corrosion rate based on periodic measurements.

3.2.6.4 Examples. Three examples have been developed to illustrate the interdependency of the factors involved in determining the expected service life of a tank. These examples illustrate how the minimum required tank wall thickness, the corrosion allowance, and the expected service life are determined. Various interactions (trade-offs) among minimum required thickness, corrosion allowance, and expected life are also presented.

Example 1. A vertical, cylindrical, welded carbon steel tank built in 1974 and used for the storage of oil is to be converted to store hazardous waste at a maximum design pressure equal to 0 psig (atmospheric pressure) and at ambient temperature. The tank, which has 72-inch butt-welded courses, was fabricated in accordance with the second edition of API Standard 650. The tank is 60 feet in diameter and 30 feet high. The oil-specific gravity is less than 1.0, and the shell plate thickness was measured to be 0.76 inch uniformly prior to the tank's being converted to store the waste. API Standard 650 specifies the following formula in calculating the minimum thickness of the tank's walls to preclude excessive stresses:

$$t_d = \frac{(2.6)(d)(H-1)(g)}{(0.85)(21000)}$$

t_d = minimum shell thickness, in inches

d = nominal diameter of tank, in feet

H = height, in feet, from bottom of course under consideration to overflow that limits tank filling or to overfilling alarm or feed cutoff trigger

g = specific gravity of liquid to be stored, but in no case less than 1.0

0.85 = joint efficiency factor for butt-welded joints (see Table 3-5)

21000 = maximum allowable tensile strength for applying the factor for efficiency of joint

$$t = \frac{(2.6)(60)(30-1)(1.0)}{(0.85)(21000)}$$

$$= 0.25 \text{ inch (approx.)}$$

As calculated above, this tank requires a minimum wall thickness of 0.25 inches to accommodate the stresses presented by oil stored in this tank to a height of 30 feet. If the tank were to be used to store hazardous waste with a specific gravity less than or equal to 1.0 and a height of 30 feet, the initial corrosion allowance would be 1/2 inch (0.76 inches - 0.25 inches = 0.51 inches).

The hazardous waste to be introduced into this tank, however, was measured to have a specific gravity of 1.2, and the owner or operator has decided to keep the minimum wall thickness of 0.25 inch in order to have the maximum 0.51 inches of corrosion allowance to prolong the service life of the tank. Because the specific gravity of the waste will place greater stress on the tank's walls, the maximum height allowed for storing the waste is calculated to be:

$$0.25 = \frac{(2.6)(60)(H-1)(1.2)}{(0.85)(21000)}$$

$$H = 24 \text{ feet (approx.)}$$

The tank in this case can only have a maximum waste liquid level of 24 feet if the maximum allowable stress is not to be exceeded. Overfilling controls should be established at this level.

The assumed hazardous waste is a salt solution contaminated by heavy metals with the most corrosive component at concentration being ferrous sulfate. Utilizing the National Association of Corrosion Engineers (NACE) table, we find that ferrous sulfate has a corrosion rate of greater than

0.05 inch per year on carbon steel. Assuming conservatively that the waste has a corrosion rate of 0.1 inches per year, we determine that the expected service life of this tank for storing this waste is calculated to be 5.1 years (0.51 inch divided 0.1 inch per year = 5.1 years). Therefore, theoretically this tank should be used to store this particular waste for no more than 5.1 years at a height not to exceed 24 feet. It should be noted, however, that a corrosion rate of greater than 0.05 inches per year is extremely high. (In most cases, a liner would be used if ferrous sulfate were to be stored in a carbon steel tank.) After an initial storage period, the actual corrosion rate should be physically measured, and by knowing the corrosion allowance and this actual corrosion rate, we can determine the expected life of a tank. The owner-operator should be required to measure the actual corrosion rate as part of the periodic assessment of the tank's condition within a given period and report it to the permit writer when renewing the permit.

As the tank approaches the end of its expected life, the owner-operator should increase the frequency of comprehensive inspections of the tank and be prepared to recoat or reline the tank; derate the tank (which means that the liquid level can be lowered to reduce the stress and, therefore, reduce the required minimum wall thickness, and increase the corrosion allowance); or introduce a new waste with lower specific gravity to reduce the stress; or prepare the tank for closure.

Example 2. An above-ground, horizontal, cylindrical welded steel tank, built in 1973 and used for the storage of gasoline, is to be converted for the temporary storage of slightly corrosive waste at ambient temperature and at a maximum internal pressure of 0.5 psig. The tank was fabricated according to the fourth edition of Underwriters' Laboratory (UL) Standard 142 with an extra corrosion allowance and installed in accordance with Flammable and Combustible Liquids Code of the National Fire Protection Association (NFPA No. 30). The tank is 144 inches in diameter and has a uniform measured shell thickness of 3/8 inch and a maximum capacity of 35,000 U.S. gallons. The hazardous waste to be stored has a specific gravity of less than 1.0 and a theoretical corrosion rate of 0.05 inch per year on the construction material of the tank.

The owner would like to store from 1,000 to 30,000 gallons of waste in the tank at a given time. The following tabulation from UL 142 indicates that a minimum thickness of 0.25 inch must be maintained to provide for structural stability to accommodate the upper volume limit of 30,000 gallons.

METAL THICKNESS - HORIZONTAL TANKS

Capacity, U.S. Gallons	Maximum Diameter, inches	Minimum Thickness of Steel, inches
550 or less	48	0.105
551 - 1,100	64	0.135
1,101 - 9,000	76	0.179
1,101 - 35,000	144	0.250
35,001 - 50,000	144	0.375

The tank, therefore, has a maximum corrosion allowance of 0.125 inch, which is 3/8 inch (current actual thickness) minus 1/4 inch (allowable minimum thickness). If the waste to be stored has a corrosion rate of 0.05 inch per year, the expected life of the tank storing 30,000 gallons of waste is 2-1/2 year (0.125 inch divided by 0.05 inch per year) prior to coating, lining, or closing the tank. Even if the tank were to be utilized to store a maximum of 1,000 gallons, however, the tank could still only be used for a period of 2-1/2 years (0.375 minus 0.250 inch divided 0.05 inch per year) because a tank that is 144 inches in diameter must have 0.25-inch minimum wall thickness, according to this standard.

Example 3. A vertical, cylindrical welded carbon steel tank is to be converted to storage of hazardous waste at a maximum design pressure equal to 0 psig (atmospheric pressure) and at ambient temperature. The tank was fabricated in accordance with the second edition of API Standard 650. The tank is 55 feet in diameter and 25 feet high. The specific gravity of the waste to be stored in the tank was measured to be 1.2. Therefore, the minimum wall thickness in inches is:

$$t = \frac{(2.6)(55)(24)(1.2)}{(0.85)(21000)} \text{ *}$$

$$t = 0.23 \text{ inches}$$

The wall thickness of the tank is nonuniformly corroded. The thickness was measured in 20 locations, and the results are given below:

1) 0.20
2) 0.19
3) 0.22
4) 0.24
5) 0.22
6) 0.20
7) 0.18
8) 0.23
9) 0.16
10) 0.20
11) 0.21
12) 0.19
13) 0.17
14) 0.17
15) 0.18
16) 0.23
17) 0.20
18) 0.22
19) 0.14
20) 0.23

At points 9, 13, 14, and 19, five additional measures were made along a longitudinal strip 4 inches long. The average measured thicknesses at these points were as follows:

9) 0.16
13) 0.18
14) 0.19
19) 0.16

The minimum of these local averages (0.16 inches) is used for comparison with the required minimum thickness.

Because the measured thickness is less than the required minimum thickness, the tank must be derated or removed from service. If it is assumed that the owner-operator decided to derate the tank, the new high level would be calculated as follows if the hazardous waste is not corrosive:

$$t = \frac{(2.6)(H-1)(55)(1.2)}{(0.85)(21000)}$$

$$H = 17.6$$

rounding down

$$H = 17$$

---

* Formula from Example 1.

In this case, the owner-operator would install overfilling controls (e.g., high-level alarms or automatic feed cutoff) at 17 feet. However, if the tank were to store a corrosive liquid, the tank should be lined or coated to prevent further corrosion because there is no corrosion allowance for the tank.

3.2.7 Tank Openings

Tanks generally will have a number of openings for such purposes as inspection (manholes), liquid inlets and outlets, liquid overflow, attachment of pressure/vacuum control devices, gas/vapor venting, etc. The various design standards have specific requirements regarding the sizes and shapes, locations, reinforcements, welding details, etc. Some of the most important features are indicated below.

3.2.7.1 Tank Openings in API 620 Tanks. In API 620 tanks, all openings in sidewalls, roofs, or bottoms shall be circular, elliptical, or obround (an obround figure is one which is formed by two parallel sides and semicircular ends). For elliptical or obround openings, the long dimensions shall not exceed twice the short dimension; the long dimension shall preferably coincide with the direction of greater stress.

Section 3.14 of the Standard prescribes how far an opening must be from other openings, from changes in geometry such as junctures between wall and bottom, from attachments such as supports, etc. Also, each opening shall be located so that any attachment or reinforcement attached to it can be made fully accessible for inspection and repair on both the inside and the outside of the tank, except in the case of connections which, for compelling reasons, must be located on the underside of a tank bottom resting directly on the tank foundation.

There are no limits of the sizes of openings, provided they satisfy the requirements outlined above and are properly reinforced, except that the largest inside dimension of an opening shall not exceed 1.5 times the smallest radius of curvature in that portion of the tank. The latter limitation does not apply to large openings centrally located on the roof or bottom of a tank with the axis of the opening coincident with the (vertical) axis of the tank.

There are special requirements for amounts of reinforcements and their weldments, for the dimensions of nozzles and their reinforcements, for bolted flange connections, and for cover plates. See Sections 3.16 and 3.17 of API 620.

3.2.7.2 Tank Openings in API 650 Tanks. Section 3.7 of Standard 650 describes the requirements for shell openings. Generally, the intent is to restrict the use of appurtenances to those providing for attachment to the shell by welding. The use of designs provided in 3.7 are required, except that connections and appurtenances complying with API 620 are satisfactory alternative designs.

Section 3.7 describes in detail the requirements for reinforcement and welding, spacing of welds, thermal stress relief, shell manholes, shell nozzles and flanges, flush-type cleanout fittings and shell connections, and inspection of welds.

3.2.8 Tank Diagrams and Data Sheets

To describe the tank, nozzles, and selected process data, the permit applicant may submit a completed form such as is presented as Figure 3-3. Alternatively, copies of the original tank specification sheet used for purchase of the tank might be provided along with a definition of the use of each nozzle; a sample of such a tank specification sheet is presented in Appendix L of API 650. Similarly, a simple tank diagram illustrating the location of nozzles and instrumentation may be prepared by the applicant, or the diagram or sketch of the tank submitted with the original tank specification sheet may be modified and used for the permit application.

An example of a tank diagram is given in Figure 3-4.

Process Information
Operating Data

Loc. or Nozz.	Fluid	Flow, Lb/Hr	Density Lb/Ft^3	Temperature, F, Norm Max/Min	Press., psia Norm Max.	Time	LL Data for
1	Liq&Vap	4539	0.754 (Max.)	95	16.2	Residence 3.0 Min.	Level Control High (LCH) High Liquid Level (HLL) Level Alarm-High(LAH) Normal Liquid Level (NLL) Level Alarm-Low (LAL) Low Liquid Level (LLL) Control Low (CL) Low Control Level (LCL)
2	Vapor	3499	0.584	95	16.2		
3	Liquid	1040	40.3 (Min.)	95	16.2		

Vapor Pressure @ Max. AMB, °F = PSIA
Process Contaminents

Mechanical
Design Requirement

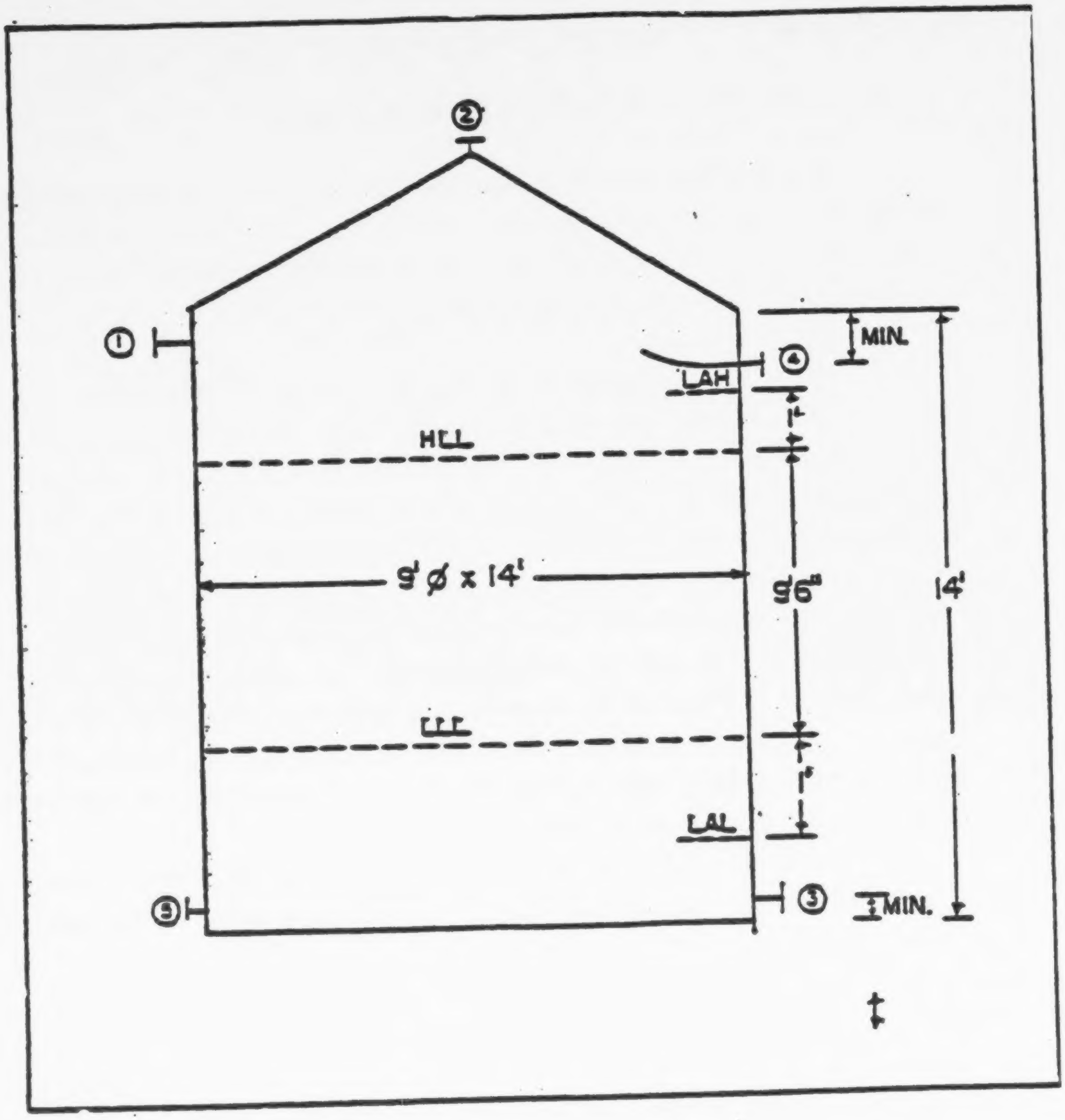
Press Margin: Min. Spec. _______ + _______ = PSI
Min. Design Press. at Top _______ PSIG (Marg. + Oper.)
System PSV Set at _____ PSIG Located
Min. Design Temp. _____ °F @ PSIA
External Press. Design:
Vessel Support Data: Skirt _____ Legs _____ Lugs _______ Saddles _______
Height _____ Min. Abv. Grade Fireproofing _______

Nozzles

	Nozz. No.	Service	No. Req'd.	Est. Size	Rating & Facing	Int'l Type or Note
Instruments	J-6	Manway				
	J-5					
	J-4					
	J-3					
	J-2					
	J-1	PSV				
Process	8					
	7					
	6					
	5	Drain	1	2"		
	4	Overflow	1	4"		
	3	Liquid	1	2"	20 FPS/1.4 psi/1000 ft.	
	2	Vapor Out	1	4"	20 FPS/1.4 psi/1000 ft.	
	1	Liq.&Vapor Feed	1	4"		

PSV = Press Sensing Valve
FPS = Feet Per Second

FIGURE 3-3. TYPICAL TANK DATA SHEET


②
①
④
LAH
MIN.
1'
HLL
9'Ø x 14'
9'6"
14'
LLL
1'
LAL
⑤
③
MIN.

Source: Fred C. Hart Associates, Inc.

FIGURE 3-4. A SIMPLE TANK DIAGRAM

Note: Circled numbers refer to nozzle numbers.

H11 = high liquid level; LAH = level alarm high; LLL = low liquid level
LAL = Level alarm low.

3.2.9 Inspection and Evaluation of Welds (Seams)

Title 40 CFR 264.19(a) requires the Regional EPA Administrator to review design of the tanks including seams. The following discusses the issues involved for tanks built to standards, those not built to standards, and both new and used tanks.

3.2.9.1 Tanks Built to Standards. Tanks which have been built to recognized standards such as ASME Section VIII, API 620, API 650, UL 58 or UL 142 will have been inspected and tested according to the requirements of the particular standard. The ASME and the API standards are very specific in their requirements regarding qualification of welders and of welding procedures, and also regarding inspection and testing of welds and of the vessels. The UL standards specify types of acceptable welded joints, including geometric details and dimensions, but are not specific about qualification of welders or of welding procedures. The final test specified by UL 142 and UL 58 is a leak test: either air pressure between 5 and 7 psig together with a leak-finding fluid, or filling the tank with water plus an additional 5 psig overpressure.

It is reasonable to assume that a new tank built to a recognized standard does not require additional inspection or tests of the welds beyond those required to meet the standard.

3.2.9.1.1 Used Tanks. For used tanks which were built to standards such as those mentioned above, evaluation of the welds in the used condition involves problems similar to those discussed elsewhere regarding the walls and the floor. See Sections 4.1.1 and 4.1.2 for guidance on methods of inspection and particular features to be measured or observed. Of course, in the present context, the application should include specifically a description of the conditions of the welds, and should indicate the methods of inspection used to determine the conditions.

3.2.9.2 Tanks Not Built to Standards. Evaluation of welds in tanks not built to a recognized standard involves similar problems to that discussed in Section 4.3 for rectangular tanks. According to 40 CFR 264.191(a), the

Regional EPA Administrator will rely on appropriate standards and other available information in the reviewing and permitting process. Since we are concerned here with evaluation of tanks and welds which were assembled without reference to a standard, the burden will be on the applicant to provide sufficient data on the materials, design, welding procedures, welder qualification, weld inspection methods and results, such that the tank may be reviewed in detail by a qualified engineer. The permit writer should anticipate that review will require an engineering analysis at the completeness-check phase and at the technical evaluation phase.

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4.0 USED, NON-METAL, AND OTHER TANKS

Chapter 3.0 dealt with the permitting of new metal tanks with emphasis on the types most likely to be used in hazardous waste storage facilities. If the permit application is for a new facility that will use only new standard metal tanks, then the permit writer would not need to refer to this Chapter 4.0 which deals with used tanks, non-standard metal tanks, and tanks constructed of non-metallic materials of construction. The standards and codes are well developed for new metal tanks and the approach in permitting such tanks can be "by the book". Conversely, less guidance is available for the material presented in Chapter 4.0 because codes and standards have not been as well developed.

More specifically, the subjects addressed in this Chapter include:

4.1 Used Steel Tanks
4.2 Fiberglass-Reinforced Plastic Tanks
4.3 Rectangular (Polygonal) and Other Non-Standard Metal Tanks
4.4 Concrete Tanks

Other types of tanks could have been addressed in this chapter such as wood and solid plastic tanks, but these have been omitted because they are not likely to be encountered in sufficient frequency to justify preparation of guidance. If a permit application with such a tank is encountered, the permit writer should anticipate that some special study will likely be required in the permitting process, and the applicant should provide adequate engineering detail to support their permitting.

4.1 Used Steel Tanks

When permitting an existing hazardous waste storage facility, the tanks are obviously in used condition at the time the permit is sought by the applicant. Furthermore, used tanks may be acquired for use in a new hazardous waste facility.

When permitting used tanks, ask two types of questions as follows:

1. If the tank were new, would the tank be suitable for the proposed use in terms of pressure, materials of construction, and other design aspects? What would be specified by the

permit writer for the minimum shell thickness and the inspection frequency? (See Chapters 3.0 and 8.0).

2. Based on recent tank inspection information, does the tank need to be repaired, derated, or removed from service?

The remainder of this section discusses used steel tanks, although the approach is generally applicable to other types of tanks. For a used steel tank, applicant should provide the following data:

1. Design standard used and its date or edition number
2. Dimensions of tank
3. Shell thickness
4. Steel specification and grade
5. Description of condition of tank, especially degree and type of corrosion from past service
6. Type and quality of foundation and tank supports
7. Proposed operating conditions, i.e.,
   Identity of liquid to be stored
   Density of liquid
   Corrosivity of liquid and compatibility with tank materials
   Maximum height of liquid
   Temperature of liquid
   Vapor pressure of liquid at storage temperature
   Pressure in gas/vapor space.
8. Complete documentation of any sampling and testing procedures used to establish characteristics of tank materials such as sampling procedures and analytical and testing laboratory reports.
9. Description of inspection procedures including extent of coverage of internal and external surfaces, degree of inspection of welds, valves, vents, gaskets or seals whether paint coatings, linings, or insulation was partially or totally removed and results of inspection.
10. Description of any remedial measures planned or performed to offset defects from past service or those involved in inspection.

4.1.1 Inspection Procedures

Inspection of used tanks intended for storage of hazardous wastes will be required in order to determine the conditions of the tank, its foundations, and appurtenances, as these may have deteriorated due to service. Reasons for inspection, particular features to be observed and measured, tools required, etc. are discussed fully in the API Guide for Inspection of Refinery Equipment, especially Chapter XIII, Atmospheric and Low-Pressure Storage Tanks. Chapter XIII covers these major topics:

- Descriptions of Types of Tanks
- Reasons for Inspection and Causes of Deterioration
- Frequency and Time of Inspection
- Methods of Inspection and Limits and Tools
- Methods of Repair

Other pertinent chapters include:

- Chapter II - Conditions Causing Deterioration or Failures
- Chapter IV - Inspection Tools
- Chapter XI - Pipe, Valves, and Fittings
- Chapter XII - Foundations, Structures, and Buildings
- Chapter XVI - Pressure-Relieving Devices

4.1.2 Description of Condition

The inspection procedures (see 4.1.1) should yield a description of the condition of the tank required for the review. Specifically, in addition to data demonstrating that the tank is in good condition, the inspection report should give (1) the actual thickness of steel in the vertical wall and the location of where it is thinnest, and (2) similar data for the bottom. These data will provide the basis for determining a minimum wall thickness to sustain the operating stresses and for determining how much corrosion allowance will exist initially.

The methods available to determine wall thickness include ultrasonic and radiographic techniques and the more traditional method of drilling and direct mechanical measurement using a hook gauge. While the first two methods are more modern and sophisticated, they are also more complex. The traditional method of drill, measure, and plug (with a threaded plug) has beeen practiced for many years; properly done, it offers no more potential detriment to tank integrity than other shell penetrations for pipes, gauges, etc.

The applicant may measure and report thickness of each course of metal plate in the vertical wall of a large API 620 or similar tank. In such cases the permit writer must specify the minimum shell thickness for each course based on a method such as is presented in Section 3.2.5.1 recalling that the pressure imposed on the vertical wall of a tank at any level is proportional to the height of liquid above that level. After such calculations have been performed, it will become possible to calculate the remaining corrosion allowance for each course. This later data will be useful in estimating the remaining service life and in specifying the inspection frequency as discussed in Section 8.6 of this manual.

4.1.3 Estimation of Adequacy of Shell Thickness

Adequacy of wall thickness can be estimated as follows:

1a. If applicant has provided data giving steel specification and grade, reviewer can calculate t_s for each course of the tank wall by the methods of 3.2.5.1.

1b. In cases where steel specification and grade are unknown, require applicant to determine an equivalent specification and grade by measuring chemical composition and mechanical properties on samples taken from tank (see following discussion on sampling). Analogous procedures for new unidentified tank materials are described in API standard 650, Appendix N and in API Standard 620, Appendix B. The taking and testing of specimens are to be performed by a qualified testing laboratory; repair of the areas from which specimens are taken should be done by a qualified welder using steel material and procedures appropriate to a suitable design standard and the planned operating conditions. Given a specification and grade for the steel in each course, a value of t_s can be calculated as in 1a above.

2. Compare the calculated values of t_s with the actual minimum thickness of each course as reported from the inspection. Any excess of actual minimum thickness over the calculated t_s for a course can be considered to be a corrosion allowance for that course. The least such corrosion allowance for all the courses may be used as the corrosion allowance for the tank.
3. If the comparison in 2 shows for any course that the calculated t_s is greater than the actual minimum thickness, then the permissible maximum height of liquid in the tank must be reduced to a value which will yield an acceptable corrosion allowance. See 3.2.5.1, Equation 5.

As partially indicated in the discussion of determining shell thickness, samples may be taken from a tank for chemical analysis or even for determination of mechanical properties; sampled locations, when properly repaired, represent little significant difference in characteristics from original tank attachments or penetrations. The safety factors implicit in allowable stress levels and in weld efficiency factors allow for initial tank fabrication and subsequent repairs.

Typically, a sample for chemical analysis would be obtained in the form of drill chips and be on the order of five grams or less in size. Judicious selection of sample numbers and locations would be part of the exercise of material identification. The sample(s) should truly reflect shell composition, i.e., not weld metal; any traces of surface coatings or contamination should be discarded or avoided during sampling.

If samples for mechanical property tests are taken, choice of test specimen size would be involved and might, for example, allow for test specimens in the range of 1" x 8" to 2" x 12" for tensile testing. Once the properties of the shell are determined, a repair with suitable materials and welding (if a metal tank) procedures can be defined. Again, a judicious choice of sample numbers and location should be evidenced, with consideration for measurement of representative properties and reliability of repair.

4.1.4 Use of Tank History

It may be impractical for the permit applicant to provide a recent technical description of condition as described in sections 4.1.2 and 4.1.3 above. For example, the applicant may be processing hazardous wastes in an existing facility using tanks that were purchased new several years ago or using tanks that were installed (or used in place) after having been used for other service.

The applicant may believe it premature to stop processing wastes for a detailed tank inspection.

Under carefully selected conditions, the permit writer may accept a tank history in lieu of a recent inspection. The primary condition would be that it is not timely to require that a tank inspection be performed based on the permit writer's judgment of the required frequency of tank inspection described in section 8.6 of this manual. Of course, if other chemicals or liquids have ever been stored or processed in the tank since the detailed description of tank condition was prepared, then the presumed corrosion rate under that condition and the possibility of non-uniform corrosion must also be defined. Nevertheless, the permit writer should require that tank inspections be performed in the future consistent with a preconceived schedule.

4.1.5 Estimation of Service Life of Used Tanks

Examples of how to estimate the expected service life of used tanks were presented in a prior section of this manual--3.2.6.4.

4.2 Fiberglass-Reinforced Plastic Tanks

Fiberglass-reinforced plastic tanks (FRP tanks) are frequently encountered in permit applications because they are relatively inexpensive and have excellent "corrosion" resistance to many chemicals. Unfortunately, the only "official" standard issued about FRP tanks was for underground storage of petroleum based fuels and oils at atmospheric pressure; this standard was issued by ASTM. In addition, UL has proposed a standard for nearly the identical service. Thus, the standards and codes for FRP tanks have not been well developed.

Part of the problem in preparing such codes or standards is that a very large array of specific plastic materials or formulations can be used as the "corrosion" barrier and as the matrix material to bond the fiberglass; many different forms of fiberglass may be used, including chopped individual fibers, woven mats, and highly oriented filament winding; and several fabrication methods are available. The standards that have been written to date do not provide design procedures, but rather, impose performance requirements and cite some specifications.

Many of the FRP tanks to be used in hazardous waste facilities are likely to have been fabricated according to the specification issued by the manufacturer of the tank. The permit writer should be prepared for cases in which no reference to the ASTM (or tentative UL) standard is made by the tank manufacturer in a tank specification. In many respects, the FRP tank specifications issued by a manufacturer are likely to be similar to ASTM D4021-81 or UL 1316 (tentative); however, the manufacturer is likely to be much more specific about standard materials, fabrication methods, tank sizes and configurations available, and other design details. The ASTM and tentative UL standards are presented in the next section.

4.2.1 Standards and Codes

Fiberglass-reinforced plastic tanks intended for use in the petroleum or chemical processing industries may be specified to meet certain codes or standards, such as ASTM or UL.

4.2.1.1 ASTM D4021-81

Title: "Standard Specification for Glass-Fiber-Reinforced Polyester Underground Petroleum Storage Tanks"

Scope: Specification covers fiberglass-reinforced horizontal, cylindrical, and spherical-type underground tanks for atmospheric pressure storage of petroleum-based fuels and oils. The specification covers the materials, the manufacture, workmanship, external load requirements, internal pressure, fitting-moment load and torque load ratings, leakage, internal impact resistance, chemical resistance, quality control, and test methods.

4.2.1.2 UL 1316 (Tentative)

Title: "Proposed First Edition of the Standard for Glass-Fiber-Reinforced Plastic Underground Storage Tanks" (January, 1982 draft)

Scope: These requirements cover spherical or horizontal cylindrical, atmospheric-type tanks of fiberglass-reinforced plastic (FRP) that are intended for the underground storage of petroleum-based flammable and combustible liquids. These tanks are completely assembled and tested for leakage before shipment, and intended for installation and use in accordance with the Standard Installation of Oil-Burning Equipment, NFPA No. 31, and the Flammable and Combustible Liquids Code, NFPA No. 30. The standard allows for the incorporation of manholes; therefore, 40 CFR 264.191(a) which states "The regulations of this Subpart [Subpart J - Tanks] do not apply to facilities that treat or store hazardous wastes in covered underground tanks that cannot be entered for inspection", will remove from consideration those tanks fabricated without manholes.

4.2.2 Evaluation of Fiberglass-Reinforced Plastic Tank Applicability

The regulations in Title 40 CFR were not written with the use of fiberglass-reinforced plastic (FRP) tanks in mind. Metal tanks fail by the process of corrosion or erosion that involves the removal of metal from the plates of the tank, and the concept of minimum shell thickness is generally valid; both of these processes result in metal thinning. Conversely, FRP tanks may fail by processes that actually swell the plastic and eventually allow delamination of the tank. Thus, the concept of minimum shell thickness is not directly applicable to FRP tanks. Furthermore, unless metal tanks are clad, lined or coated, the standards, by implication, are able to assume that the metal is homogeneous for design computations. (Actually, metals are not homogeneous on a molecular or crystalline basis.) Conversely, as indicated previously, most FRP tanks are really fabricated as laminations that may involve several plastic formulations, several forms of fiberglass, and several techniques of fabrication in each tank. Thus, the tank cannot be conceived of as being of a homogeneous material. Many different proprietory materials and procedures are available to the manufacturers of such tanks. Because of these facts, it is impractical for the permit writer to consider use of design procedures or computations to verify the adequacy of tank design.

Based on the above information, it is clear that the permit writer must rely on information submitted by the permit applicant to determine the applicability of a specific FRP tank to a given hazardous waste service. Such information submitted by the applicant should preferably be copies of a tank specification and/or other engineering information submitted by the tank manufacturer to the applicant about the tank purchased and its applicability to the intended service. That is, the applicant should have requested a tank using materials of construction compatible with the specific hazardous waste, under specific maximum operating conditions of pressure, temperature, and liquid level; if the specific gravity of the liquid were greater than 1 (62.4 lbs/cu. ft.), this should have been specified too. The manufacturer should have responded that the tank purchased would be suitable for such service.

The permit writer may receive less information from the applicant than the ideal presented above. In such cases, the permit writer must exercise judgement in the determination or whether the information is sufficient, specific to the application, relatively unbiased, and reflects adequate engineering analysis. Analysis of data from NACE (See Appendix E) may indicate no problem of incompatability. General brochures or specifications may be adequate if the tank is to be operated at ambient temperatures and atmospheric pressure with a liquid of a relatively low specific gravity. However, if higher pressures or temperatures are involved, or if NACE presents no data or some problem is indicated by NACE, the permit writer should use caution.

4.2.3 Minimum Shell Thickness Equivalent

FRP tanks are more likely to fail due to reaction, softening, swelling, or crazing than to wall thinning (through dissolution). Thus, the minimum shell thickness requirement should be specified such that no fiberglass shall be exposed and the tank shall show no significant deterioration upon visual inspection as evidenced by obvious wall thinning, discoloration, disintegration, crazing, softening, swelling, indentations or delamination. Many tanks will be sufficiently translucent to also inspect the tank for porosity, air or other bubbles, and other inclusions.

4.2.4 Frequency of Inspections

Because of the manner in which FRP tanks fail, the general lack of published public data on service life of such tanks, and the fact that FRP tanks have not had a long history of use, the best recommendation on frequency of inspection is likely the manufacturer of the tank or possibly others (such as manufacturers of chemicals) that have used the same or a similar plastic material formulation for the corrosion barrier to contain similar liquids. The tank manufacturer should be made aware that leaks or spills of the hazardous waste are intolerable and must be avoided through adequate inspections. Generally, the permit applicant should be required to obtain such information from the manufacturer and incorporate it in the permit application for FRP tanks.

In specifying the inspection frequency, the permit writer should not be unduly concerned about using relatively long inspection periods if the plastic used is not attacked by the hazardous waste. Service life under these conditions could be indefinite. Furthermore, upon detection of significant deterioration, the tank should either be repaired or removed from service; the concept of the wall thinning to the minimum shell thickness is not applicable to FRP tanks.

Similar to the situation for metal tanks, there are certain practical considerations that the permit writer can apply in establishing the frequency of inspection. (See section 8.6.2.)

4.2.4.1 Immersed Test Specimens.

Users of FRP tanks for liquid storage should be encouraged to use appropriate test specimens immersed within the tank as indicators of the tank condition if the compatibility of the plastic with the liquid is uncertain. Such specimens may not only be visually inspected, but also tested for strength, hardness and weighed either for weight gain or loss. Further discussion indicating the general concept (for metal tanks) is presented in Section 8.6.2.2 of this manual.

4.2.4.2 External Inspections. External inspection of FRP tank is not effective in the determination of the condition of the interior. Therefore, more frequent detailed external inspections would have no practical impact on the desired frequency of internal inspections.

4.3 Rectangular (Polygonal) and Other Non-Standard Metal Tanks

Permit applications may be prepared for facilities that use or may use, non-standard metal tanks. Although such tanks may be entirely suitable if they are properly designed, special problems are imposed on the permit writer in such cases. Such tanks may be fabricated in either the typical cylindrical configuration or may be composed of a large number of flat plates.

4.3.1 Cylindrical Metal Tanks

If non-standard cylindrical metal tanks are included in the permit application, then the applicant should provide all detailed drawings and design calculations to enable a mechanical (or equivalent) engineer to verify that the tank is suitable for the intended service. It may be possible for the applicant to cite a standard after which the tank was patterned if departures from such a standard are not severe; in this case, the task of review engineer may not be intensive. Conversely, if no such comparable standard is available, then the task may become burdensome and require the assistance of a tank design specialist.

4.3.2 Rectangular (Polygonal) Metal Tanks

Reviewers should anticipate receipt of applications for tanks that are not cylindrical, such as are covered by API 620 or API 650, et al, but are constructed entirely with flat plates fastened together by some means. Such tanks necessarily involve intersections of the sides with each other which are plane angles, and similarly for intersections of sides with the (flat) bottom. If the tanks are rectangular, the angles will be 90 degrees. There is no recognized code or standard for the design, fabrication, inspection, testing, or certification of such tanks.

According to 40 CFR 264.191(a), the regional EPA administrator will rely on appropriate industrial standards and other available information in the reviewing and permitting process. Since there is not an applicable code or standard for metal tanks constructed entirely with flat plates, the burden will be on the applicant to provide sufficient data on the materials, design, fabrication, inspection, and testing such that the design may be reviewed in detail by a qualified engineer. The permit writer should anticipate that review will require engineering expertise at the completeness-check phase and detailed engineering analysis at the technical-evaluation phase.

4.4 Concrete Tanks

Concrete tanks are used for storage of waters and aqueous solutions of inorganic materials, as settling tanks and may be the subject of an application. Thus, standards issued by the American Concrete Institute are presented in this section. The National Association of Corrosion Engineers also report some data for concrete (see Appendix B).

If a storage facility is to use concrete tanks for hazardous wastes then the burden should be placed on the permit applicant to provide information justifying the compatibility of the tank with the liquid, standards used in fabrication, and the engineering design computations. In addition, the applicant should provide criteria and justification for the criteria for taking the tank out of service and for a suggested frequency of inspection.

4.4.1 Standards and Codes

As with other types of tanks, such as steel tanks, the design and construction of concrete tanks is covered by various standards, depending on the intended use. The principal source of data, recommended practice, and standards for the use of concrete is the American Concrete Institute (ACI) (address: Box 19150, Redford Station, Detroit, MI 48219). The ACI publishes various standards, guides, reports, etc, each of which is available separately. The ACI also publishes periodically its ACI Manual of Concrete Practice which is a large, three-part reference work containing the current editions of standards, guides, reports, etc. The contents of the ACI Manual of Concrete Practice (1979) are current committee reports and standards concerned with:

Part 1: Materials and Properties of Concrete
Construction Practices and Inspection
Pavements and Slabs

Part 2. Notation and Nomenclature
Structural Design
Structural Specifications
Structural Analysis

Part 3: Products and Processes.

The scopes of those items considered most pertinent for EPA reviewers are summarized below.

4.4.1.1 ACI 318-77

Title: ACI Standard, Building Code Requirements for Reinforced Concrete

Scope: This is the basic standard for the proper design and construction of buildings of reinforced concrete. It covers (1) standards for tests and materials, (2) concrete quality, (3) mixing and placing concrete, (4) formwork, embedded pipes, and construction joints, (5) details of reinforcement, (6) analysis and design, and (7) structural systems. The code provides minimum requirements for design and construction of reinforced concrete structural elements of any structure erected under requirements of general building codes, but does not specifically cover tanks. The code states that for special structures, including tanks, provisions of this code shall govern where applicable.

4.4.1.2 ACI 350 R-77

Title: Concrete Sanitary Engineering Structures

Scope: As indicated by "R" in the ACI designation, this is for a committee report, and as such contains recommendations for structural design, materials, and construction of concrete tanks, reservoirs, and other structures commonly used in water and waste treatment works where dense, impermeable concrete with high resistance to chemical attack is required. Special emphasis is placed on designs which minimize cracking and accommodate vibrating equipment and other special loads. Chapter 5 - Protection Against Chemicals - states that concrete made with the proper type of cement, which has been properly proportioned, mixed, placed, and cured, will be dense, strong, watertight, and resistant to most chemical attack; therefore, under ordinary service conditions, quality concrete does not require protection against chemical deterioration or corrosion. However, in industrial waste treatment plants, where the pH of acid waste may go as low as 1.0, the types of protection generally used are chemical-resistant mortar, acid-proof brick or tile, thick bituminous coatings, epoxies, and heavy sheets or liners of rubber or plastic.

4.4.1.3 ACI 201.1 R-68

Title: Guide for Making a Condition Survey of Concrete in Service

Scope: This guide provides a system for reporting on the condition of concrete in service. It includes a check list of the many details to be considered, and provides standard definitions (with pictures) of 40 terms associated with the durability of concrete.

4.4.1.4 ACI 311-75

Title: Recommended Practice for Concrete Inspection

Scope: This document sets forth standards and procedures relating to concrete construction which will serve as a guide to owners, architects, and engineers in planning inspection programs.

4.4.1.5 ACI 311.1 R-75

Title: ACI Manual of Concrete Inspection

Scope: This 275-page book is intended as a supplement to specifications and as a guide in matters not covered by specifications. It includes information on inspection fundamentals, proportioning and control of mixes, testing of materials, inspection before, during, and after concreting, sampling, and tests of fresh and hardened concrete.

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CHAPTER 5

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5.0 TANK ANCILLARIES
PRESSURE AND OTHER CONTROL SYSTEMS

In brief outline format, the Title 40 CFR regulations require the following pertaining to design of pressure and other control systems:

- A diagram of piping, instrumentation, and process flow [270.16(d)]
- Description of feed systems, safety cutoff, bypass systems, and pressure controls [270.16(e)]
- Review of the design of pressure controls for closed tanks to assure that they do not collapse or rupture [264.191(a)]
- Use of appropriate controls and practices to prevent overfilling [264.192(a)(2)].

All such control systems should be diagrammed on a piping and instrumentation diagram (P&ID), which was described in an earlier section of this manual (Section 2.2).

Internal pressure and pressure controls are presented in Section 5.1 and other controls and instruments are presented in Section 5.2 of this manual.

5.1 Internal Pressure and Pressure Controls

Tanks are designed to withstand working or design pressures (or vacuum—an external pressure) up to specified limits as indicated in Section 3.2 of this manual. Tanks designed according to standards or codes often appear to have inherent theoretical safety factors in the range of about 3 to 5; however, the reason the standards were initially developed was because failures were occurring with smaller safety factors. Thus, the acceptable working or design pressures should not be significantly exceeded under plant operating conditions. (Nevertheless, tanks and pressure vessels are frequently hydrostatically tested with water under safe conditions at about 150 percent of the design pressure.)

The following sections briefly discuss internal pressure, venting or pressure relief, and vapor recovery systems.

5.1.1 Internal Pressure

For an open (uncovered) tank, the only pressure imposed on the tank is that due to the hydrostatic head imposed by the height (or head) of the contained fluid. Engineers may measure this literally as feet of water or contained fluid. Conversion to a more conventional pressure unit, pounds per square inch (psi), is accomplished by multiplying the feet of head by the density of fluid in pounds per cubic foot, divided by 144 to convert pounds per square foot to pounds per square inch; for example,

$$\text{1 foot of water} = \frac{\text{(1 foot) (62.4 pounds/cubic foot)}}{\text{(144 square inchs/square foot)}}$$
$$= \text{0.433 psi.}$$

A closed tank will normally have a pressure at least equal to the hydrostatic head plus the vapor pressure at storage temperature of the contained liquid. Vapor pressures may be determined for many chemicals and other liquid products by reference to standard handbooks; nevertheless, the permit applicant should provide the vapor pressures for the volatile liquids (or mixtures) to be stored in the facility. Such vapor pressures are often cited in units of millimeters of mercury (mm Hg) or atmospheres (atm) and may be converted to psi by knowledge that the following are equivalent:

760 mm Hg = 1 atm = 14.7 psi.

However, the pressure in closed tanks can be increased to hazardous levels due to a number of other factors including:

- Forwarding liquid or gas into the otherwise closed tank from a higher pressure source such as a pump, compressor, or gas cylinder

- An increase in the storage temperature resulting in increased vapor pressure because of an increase in ambient temperature, the introduction of hot fluid to the tank, tank overheating, or exposure to fire.

Similarly, the pressure in the tank may be reduced by the converse of the above; that is,

- Pumping or draining the liquid out of an otherwise closed tank
- Reducing the liquid storage temperature such as caused by a decrease in ambient temperature.

In some cases, pressure reduction may be sufficient to create a vacuum in a tank such that the tank will collapse due to the external pressure imposed by the atmosphere on the tank.

5.1.2 Venting or Pressure Relief

Venting or pressure relief for tanks performs two general functions:

- Allows air, inert gas, or other blanket gas into the tank or allows vapor to escape from the tank. In this manner the internal pressure of the tank will be maintained either at atmospheric pressure or within the pressure limitation of the tank design to preclude rupture or collapse of the tank.
- Serves as a collection point for vapor emissions. Such vapor emissions may then be recovered or treated to avoid emission to the environment.

Venting or pressure relief devices for use on petroleum product tanks are categorized by API Standard 2000 "Venting Atmosphere and Low-Pressure Storage Tanks", as either normal or emergency vents.

Normal vents include:

- Pilot-operated relief valves (of a fail-safe type, which excludes use of the weight and lever type)

- Pressure relief valve (for tanks operating above atmosphere pressure)
- Pressure vacuum valve (for tanks where a vacuum can be created)
- Open vents with flame arrester (for petroleum products with flash points below 100 F or on tanks where the oil is heated above the flash point)
- Open vents (for petroleum products with flash points above 100 F, tanks where the oil is heated but below the flash point, or tanks less than 2500-gallon capacity of petroleum products)

Emergency vents include:

- Larger or more open vents, but only where open vents may be used
- Larger or more pressure vacuum valves or pressure relief valves
- A gage hatch or manhole where a cover will lift if high internal pressure is experienced
- A weak seam connection between the roof and shell of the tank
- Other forms of construction comparable for pressure relief purposes (rupture or frangible disks, which are thin metallic disks, presumably fit this category).

Required venting capacity of the devices expressed in terms of cubic feet of free air per hour for both "normal" and "emergency venting for fire exposrue" is presented in API Standard 2000, Sections 2 and 3, respectively. NFPA 30 also presents comparable information in Sections 2-2.4 and 2-2.5, respectively.

5.1.2.1 Venting and Pressure Control for API Standard 620 Tanks. Tanks built to the design rules of API Standard 620 shall be equipped, within the pressure limits of the standard, with pressure-relieving and emergency vacuum-relieving valves. The standard stipulates specific limits of pressure excursion above the maximum allowable working pressure, for the provision of supplementary pressure-relieving devices where a tank may be exposed to accidental external fires, and contains recommendations regarding the materials, the construction, and types of devices.

A tank which is likely to operate completely filled with liquid shall also be equipped with one or more liquid-relief valves at the top of the roof.

The relieving devices for gases, if not on the roof, shall be installed on the connected piping, if any, as close to the tank as practical; and if vented to atmosphere, at a sufficient height to prevent any chance of ignition (see API Standard 2000: "Venting Atmospheric and Low-Pressure Storage Tanks").

5.1.2.2 Venting and Pressure Control for API Standard 650 Tanks. Appendix F of API Standard 650 provides for the design of closed-top tanks to operate with small internal pressures, up to a maximum of 2.5 psig. Such tanks shall have vents sized and set so that at their rated capacity, the internal pressure under any normal operating condition shall not exceed either the internal design pressure, P, or the maximum design pressure, P_{max}. For definitions of these pressures and methods of their calculation, see Section F.5 of the Standard.

For certain design conditions specified in F.2.2 of the Standard, emergency venting devices conforming to API Standard 2000 shall be provided.

5.1.3 Vapor Recovery Systems

Vapor recovery systems have sophisticated pressure-sensing and pressure-control instrumentation that maintains vapor pressure equilibrium during all periods ot tank operation. These systems collect the vapors and are frequently followed by a treatment process that either renders the vapor harmless for venting to the atmosphere or converts it to a product that has market value. The liquid may also be recycled. Common treatment methods include compression, absorption, and condensation. If the product has no value, it can be disposed of by flaring, incineration, or other methods. Two configurations of vapor recovery units are used: (1) individual units for each tank and (2) common vapor recovery units for a system of two or more tanks that are being used to store wastes with similar vapor chemical compositions.

The following items should be considered when evaluating vapor recovery systems:

- When more than one type of waste is handled, compatibility must be determined; when the wastes are incompatible, their vapors may also be incompatible and separate vapor recovery units would be appropriate.
- Vapor recovery systems must be maintained at airtight conditions to preclude leakage.
- The vapor recovery pipes should be sloped down to a common place where condensation can be collected. In addition, the linear velocity of vapor must be maintained under design limitation to preclude excessive turbulence, vibration, etc.

The permit writer should review the process flow diagram (PFD) that depicts the direction of vapor and fluid movements to evaluate factors such as the following:

- Is there a vapor recovery system or other method of recovery to accommodate incompatible wastes? (Incompatible wastes should not utilize a common vapor recovery system.)
- If compatible wastes are going to be handled, are there separate piping systems?

5.1.3.1 A Common Vapor Recovery System. A common vapor recovery system which connects all the tanks and process equipment in a facility collects all excessive vapors generated and disposes of them in an environmentally acceptable manner (treatment system flaring, etc.). It consists of an interconnecting piping system with manifolds and headers linking all the vents, plus pressure and temperature instrumentation. The common vapor recovery header serves to form a pressure-balancing system.

The design of a common vapor recovery system requires the following information:

1. Properties of the Fluid. The properties of fluid in storage, especially the degree of volatility, are directly linked to the header size. For example, relevant fluid properties of facilities storing hydrocarbons include the fluid specific gravity, the flash point temperature, weight percent solids, weight percent water, viscosity at the storage temperature, amount of dissolved inert gas, amount of dissolved and free phase water, and the vapor pressure at storage condition.

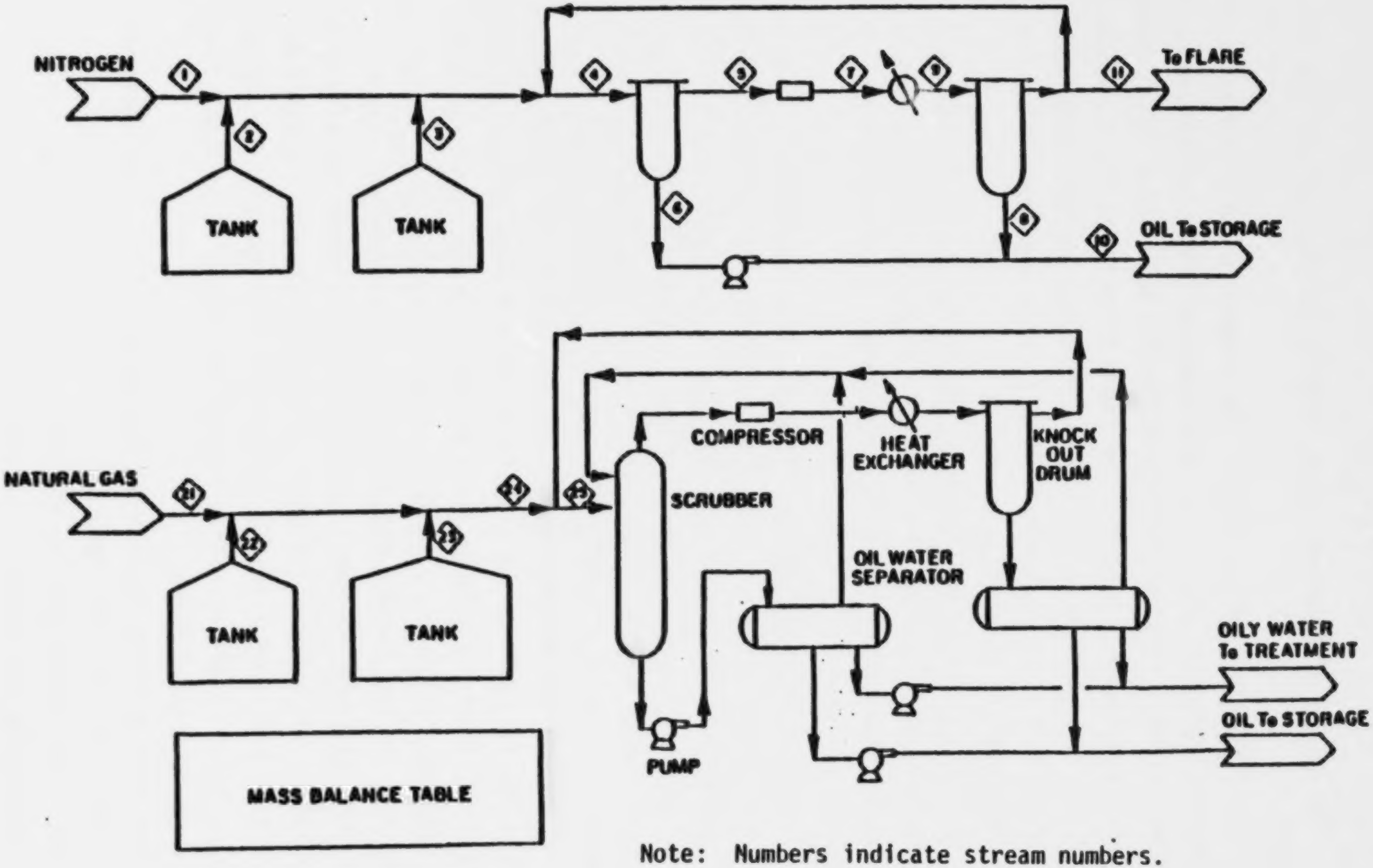
2. Design and Normal Operating Conditions. The design and normal operating conditions of the facility, primarily temperature and pressure, are linked to the breathing requirement. The breathing in turn affects the header size.

3. Capacity Requirements. The capacity requirements refer to the vapor recovery system's vents. They must be designed to accommodate the expected volumetric flow rate, e.g., fill rate when pumping.

4. Vapor Recovery Methods. Vapor recovery methods, such as compression, cooling, or the combination of both, affect the venting design. The selection of a recovery method is primarily dictated by cost.

An example of a common vapor recovery system for an oil refinery storage facility is shown on the simplified process flow diagram (Figure 5-1). Crude oil from shipment is first stored in tanks, then pumped to different treatment units and refined into gasoline, kerosene, diesel, and other products. On the process PFD, each stream is numbered. In a complete PFD, a mass balance table would also be included; the sizing of tanks, pipelines, and process equipment is always based on the maximum flow. Note that the tanks are either blanketed with nonreactive gas or natural gas. Under normal operating conditions, there is no vapor from nonreactive gas-blanketed tanks.

The vent gas from the tanks flows to the first stage knockout drum. Upon entering the drum, some mist condenses and is collected at the drum bottom and pumped back to the storage tanks. The vapor is condensed by compression and cooled by a heat exchanger. The condensed liquid is collected at the liquid recovery drum bottom and pumped back to the storage tanks. The non-condensed vapor is sent to a flare. The


NITROGEN
TANK
TANK
To FLARE
OIL To STORAGE
NATURAL GAS
TANK
TANK
COMPRESSOR
HEAT EXCHANGER
KNOCK OUT DRUM
SCRUBBER
OIL WATER SEPARATOR
OILY WATER To TREATMENT
OIL To STORAGE
PUMP
MASS BALANCE TABLE

Note: Numbers indicate stream numbers.

Source: Fred C. Hart Associates, Inc.

FIGURE 5-1. SIMPLIFIED PROCESS FLOW DIAGRAM, COMMON VAPOR RECOVERY SYSTEM

natural gas blanket and tank vapor goes through a scrubbing process before going through the compressor-knockout drum recovery process.

5.2 Other Controls and Instruments

Section 5.1 discussed internal pressure, pressure controls, and vapor recovery systems. The purpose of this section is to discuss other controls and instruments. However, it should be noted that some of the controls discussed in this section may be related to pressure controls. For example, if the temperature rises in a closed tank containing a volatile liquid, then the pressure will rise; however, the temperature may be controlled by cooling the contents of the tank with cooling water and, thus, reduce the pressure.

As was mentioned previously, all such control systems should be diagrammed on a P&ID and, as required in 40 CFR 270.16(e), the applicant should present a description of the feed, safety cutoff, and bypass system. Title 40 CFR 264.192(a)(2) requires the use of appropriate controls and practices to prevent overfilling.

Process control is a very complex subject that is far beyond the scope of this manual; for example, Perry's Handbook (Chemical Engineers' Handbook, Fifth Edition, R. H. Perry and C. H. Chilton, Editors, McGraw-Hill, New York, 1963) presents a 148-page chapter on the subject which is an excellent summary. Therefore, this section of the manual should be considered very elementary and pragmatic in nature.

5.2.1 Process Control—Simplified

The following presents a very simplified description of a typical process control system to illustrate the principles involved.

The first step is to sense (or measure) that some process condition such as temperature, pressure, flow rate, level, physical property (density, viscosity, etc.), or chemical analysis is either desirable or undesirable. Such a sensing device may create a signal that is convenient for use, such as a thermocouple generating a voltage which may be transmitted. Conversely, a liquid-level float floating on top of the surface of liquid creates no signal; however, the float connected to a lever may be used to throw a switch allowing current to flow, which signals that the level is too high (or low). Thus, the second step may be to convert the action of the sensing device to a signal that may be transmitted; transducers are often required to perform this second step.

The third step is to transmit the signal to a control (or indicating) instrument or an alarm. If the instrument is only an indicating instrument or an alarm, all subsequent control functions must be performed manually. However, if a control instrument (or controller) is used, then in the fourth step it will generate a signal to a control device such as a control valve or pump switch. This latter signal is often either electrical or pneumatic. In addition, this latter signal may be of an on or off nature to tell the "final control element". such as a valve, to either open fully or close fully, or it may be proportional—that is, the valve should open (or close) proportional to the amplitude of the signal.

In the fifth step, the final control element may turn off a pump switch to stop a tank from overfilling because a high-liquid-level switch has been activated, or it may open a steam valve a little bit more to the shell side of a heat exchanger because the temperature inside a tank has cooled to just below an acceptable level.

Process controls can become very complex and involve feedback control where the poor operating condition is corrected by controlling some device ahead of the point at which the condition is measured. Alternatively, a feed-forward control system may be used where a poor operating condition is anticipated unless something is done; for example, if the feed rate is increased, then a control valve to allow more cooling water into a heat exchanger may be opened further to assure adequate cooling. Many chemical manufacturing plants now use computers for optimized process control.

5.2.1.1 Fail-Safe Positioning. In analyses of process control systems, the permit writer should determine that if power outages or instrument air failures were to occur, then the final control elements would position themselves in a fail-safe orientation. Control valves and electrical switches can be selected such that upon instrument air or power failure, the final control elements would be either fully on or off (or fully open or closed). Thus, the permit applicant should fully describe the position of the final control elements upon either a power or instrument air failure and present adequate discussion to indicate that such a position is the fail-safe position.

5.2.2 Process Variables Requiring Measurement

Process variables need to be measured and maintained routinely at certain values. These variables are monitored by electrical, mechanical, or chemical devices. The following measures should be taken regularly to ensure safe operation of a hazardous waste tank facility. The permit writer should determine whether or not procedures needed to measure these variables are adequate.

5.2.2.1 Temperature. Abnormal temperatures may indicate that undesired reactions are occurring in the tank, excessive heat is being generated, hazardous vapors are being emitted, etc. Excessive temperature may also cause a higher pressure in the tank.

5.2.2.2 Pressure. Measure pressure to ensure that design pressure of a tank is not being exceeded.

5.2.2.3 Flow Rate. Measure flow rate to preclude overfilling of a tank, etc.

5.2.2.4 Level. Measure level to preclude overfilling and maintain the desired liquid level.

5.2.2.5 Liquid Specific Gravity. Measure specific gravity to ensure that weight of liquid does not place excessive stress upon the tank.

5.2.2.6 Other Variables. Under specific conditions it may be appropriate to measure other variables such as pH, flash point, chemical analyses, or moisture content to assure that the system is operating properly or that the liquid is not corrosive to the tank. However, the ones mentioned above are most important to assure proper tank operation.

Refer to Perry's Chemical Engineers' Handbook, Fifth Edition, Chapter 22, for a description of measurement devices.

5.2.3 Overfilling Control Systems

Title 40 CFR 264.192(a)(2) states that tanks must be equipped with overfilling control systems. The two most important components of overfilling control, flow measurement and level measurement, are discussed below.

5.2.3.1 Flow Measurement. Monitoring of the flow rate into a tank can be used to prevent overfilling or pressure buildup due to an increase in the feed rate without a corresponding increase in the effluent rate. However, flow rate measurements alone are insufficient to prevent overfilling. A complete overfilling control system should also include at least one of the following systems:

(1) An alarm triggered by excessive flow rate and also a feed cutoff valve accessible to the operator
(2) An open by-pass line to an empty or nearly empty stand-by tank, or
(3) A feed cutoff system or alarm triggered by a liquid-level measurement device as described in the following section (5.2.3.2).

5.2.3.1. Local Static Pressure. The internal pressure on the surface of the pipe is measured by making a small internal hole perpendicular to the surafce and connecting and opening to a pressure-sensing element.

5.2.3.1.2 Velocity Meters. Pitot tubes measure local velocities by measuring the difference between impact pressure and static pressure.

5.2.3.1.3 Pressure Meters. The rate of flow through the pipe is calculated from teh pressure drop caused by a constriction such as an orifice.

5.2.3.1.4 Mass Flowmeters. The mass flow rate can be measured directly by creating angular momentum with an impeller and then measuring the torque this momentum imparts to a tubine, or the volumetric flow rate can be measured and the mass flow rate calculated using fluid density.

5.2.3.2 Liquid-Level Measurement and Control. One of the most effective means of preventing overfilling in a tank is through the use of a liquid-level measurement device connected to an alarm or automatic feed cutoff system; another effective means of preventing overfilling is by allowing the tank to overflow to another tank. Several types of liquid-level measurement devices are discussed below, any of which could be used to control a switch for an alarm or feed cutoff valve.

In some cases where float-activated (see below) devices are used, four liquid-level measuring devices may actually be installed on the tank. They include the following:

- High liquid level (HLL), which indicates when the liquid level has reached the design capacity of the tank
- Low liquid level (LLL), which indicates when the liquid level is low
- Level alarm high (LAH), which indicates when the liquid has reached the dangerous level. If the situation is not rectified, the waste will overflow from the tank.
- Level alarm low (LAL), which indicates when the liquid level has reached a dangerous level for the pump. If the situation is not rectified, pump cavitation can occur because of pumping air instead of liquid.

In other cases, when other types of devices are used, such as a head device (see below), the high and low liquid levels may be indicated as points on an instrument chart and the level alarms (high and low) activated all through one measuring device. Nevertheless, it may be prudent for the permit writer to require use of a backup high level alarm system for hazardous wastes that are particularly obnoxious.

5.2.3.2.1 Float-Activated Devices. Float-activated devices are characterized by a float on the surafce of a liquid. In one type, an electrical switch is activated by a magnetic float.

5.2.3.2.2 Displacer Device. Displacer-activated level measuring is accomplished through measurement of the buoyant force on a partially submerged float. The force on the displacer (i.e., float) can be determined by measuring compression of a spring that holds the displacer in place or through measurement of the force on a torque tube connected to the displacer by a rod. The range of a displacer device is limited to the length of the displacer.

5.2.3.2.3 Head Device. A variety of devices utilize hydrostatic head as a measure of level. The majority of these devices use differential pressure-measuring devices to measure the difference in pressure between atmospheric pressure and the pressure near the bottom of the tank.

5.2.4 Freeboard

In addition to overfilling controls, owners-operators of open tanks are required to maintain sufficient freeboard to prevent overtopping owing to wind or wave action or precipitation. In a tank of less than 100 meters in diameter, the maximum height of a wind-induced wave is often about 4 to 5 inches. Allowing another 4 to 5 inches for splashing on the sides and 6 inches for precipitation, 14 to 16 inches of freeboard would barely be adequate for most tanks; 18 inches would provide some safety factor.

CHAPTER CONTENTS

6.0 TANK ANCILLARIES: PUMPS, PIPING, AND AGITATOR STUFFING BOXES
    6.1 Pumps
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6.0 TANK ANCILLARIES: PUMPS, PIPING AND AGITATOR STUFFING BOXES

Chapter 6.0 deals with hardware-type items typically associated with tanks such as pumps, piping, and agitator seals. Chapter 5.0 dealt with instrumentation, pressure control, and process control. Chapter 7.0 will deal with tank foundations, supports, thermal insulation, and electrical grounding.

6.1 Pumps

Interim guidance is provided in the following pages, which have been copied directly from a similar manual prepared by Fred C. Hart Associates, Inc.

Pumps*

Pumps are necessary for all tank storage/treatment facilities. The cost of pumping can be a major factor in plant design and operation.

There are three broad classes of pumps: centrifugal, rotary and reciprocating. Table 6-1 summarizes pump classes and types.

Several factors must be considered when selecting a pump to handle hazardous wastes. These factors include:

1. capacity
2. pump head
3. nature of liquid handled
4. cost
5. materials of construction

1. The pump capacity requirement is determined by the liquid volume to be handled. A design safety factor is needed

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* Source: T. G. Hicks and T. W. Edwards, "Pump Application Engineering", New York, McGraw-Hill, 1971.

TABLE 6-1. PUMP CLASSES AND TYPES

Class	Type
Centrifugal	Volute
(Single-stage and multistage)	Diffuser
	Regenerative-turbine
	Vertical-turbine
	Mixed-flow
	Axial-flow (propeller)
Rotary	Gear
	Vane
	Cam and piston
	Screw
	Lobe
	Shuttle-block
Reciprocating	Direct-acting
	Power (including crank- and fly wheel)
	Diaphragm
	Rotary-piston

in case the flow exceeds the normal capacity. A stand-by pump is recommended when the flow of a particular stream cannot be interrupted.

2. The pump head requirement is primarily determined by the height the liquid must be lifted and friction losses exerted by piping and fittings.
3. The nature of the liquid handled, i.e., viscosity, volatility, corrosiveness, and amount of solids in suspension, will determine the type of pumps to be used and the construction materials.
4. Cost factors, in part, dictate the pumping scheme or type of pump acceptable to a facility. Comparison of cost factors may allow owner/operators to secure the lowest annual cost per gallon of liquid pumped. Dependability, ease of maintenance and repair, and flexibility are other factors.
5. Materials used in construction are important in the design of service pumps. Factors include corrosion-erosion resistance when transporting acids, alkalies, slurries, and other liquids, ease of installation, operation, and maintenance, and dependability. For example, a typical centrifugal pump for handling acid and slurry can be made of materials such as lead, stainless steel, solid plastic or solid rubber. When special designs are not required, rubber, teflon, or neoprene base coverings are available for the casing, and impeller.

6.2 Piping

Although there is no direct regulatory requirements that the permit writer review the piping associated with tanks, piping is such an integral part of tank systems that some analysis may involve review of piping to assure that the piping was designed for its intended use as opposed to being put together in a configuration which has significant risk of future failure. In support of such possible review, this section presents the following:

- 6.2.1 Codes and Standards
- 6.2.2 Materials
- 6.2.3 Piping Joints
- 6.2.4 Piping Supports
- 6.2.5 Valves
- 6.2.6 Inspection and Testing.

6.2.1 Codes and Standards

Piping intended for use in the petroleum or chemical processing industries is ordinarily specified to meet certain codes or standards, such as those developed by the API, the ASME, ANSI, and ASTM. Brief descriptions of those most likely to be encountered in connection with handling or storage of hazardous liquids are given below.

6.2.1.1 ANSI Standard B31.3

Title: "Petroleum Refinery Piping"

Scope: B31.3 prescribes minimum requirements for the materials, design, fabrication, assembly, test, and examination of petroleum refinery pressure and vacuum piping systems. The Code applies to systems handling all fluids, including fluidized solids, and to all types of services, including oil, gas, steam, air, water, chemicals, and refrigerants. Piping consists of pipe, flanges, bolting, gaskets, valves, fittings, the pressure-containing parts of other components, and pipe-supporting elements.

6.2.1.2 ANSI Standard B31.4

Title: "Liquid Petroleum Transportation Piping System"

Scope: B31.4 prescribes minimum requirements for the design, materials, construction, assembly, inspection, and testing of piping transporting liquid petroleum such as crude oil, condensate, natural gasoline, natural gas liquids, liquified petroleum gas, and liquid petroleum products between producers' lease facilities, tank farms, natural gas processing plants, refineries, stations, terminals, and other delivery and receiving points.

6.2.2 Materials

ANSI B31.3 permits a material to be used for piping, provided it is listed in Appendix A of the Standard, "Allowable Stresses in Tension for Materials", and meets requirements of the Code with respect to temperature limitations and design stresses. There are provisions for qualification of unlisted materials by means of engineering calculations, experimental stress analysis, proof testing, and taking into account service conditions. Reclaimed pipe or piping components may also be used, provided they conform to a specification in Appendix A and meet other requirements of the Code. Upper temperature limits generally will correspond to the highest temperature at which stress values are shown in Appendix A, a material may be used at a higher temperature provided the design engineer determines that the material is suitable for the service conditions and no prohibition appears in Appendix A. Similarly, the lower temperature limits generally are the "Minimum Temperatures" listed in Appendix A; a material may be used at a lower temperature if impact testing shows that the material has adequate toughness at the design temperatures. B31.3 has special limits and prohibitions regarding certain alloys. Section 323.2.3 also presents in great detail descriptions of impact testing methods and acceptance criteria which shall be used when impact testing is required elsewhere in the Code, or by engineering design.

ANSI B31.4 generally permits only steel for pipe, and the recognized standards for pipe steels and piping materials are listed in Table 423.1 of the Standard. Cast, malleable, and wrought iron are not to be used for pressure-containing parts except under certain specific restrictions, notably a pressure limit. Limitations on gasket and bolting materials are also covered in the Standard in Section 425.

6.2.3 Piping Joints

ANSI B31.3 on refinery piping deals with piping joints in Chapter II, Part 4. Many types of joints are permitted under the standard: welded joints; flanged; expanded; threaded; flareless and compression; caulked; brazed and soldered; and proprietary joints, all subject to stated limitations. The most important specific limitations are as follow.

Welded joints - may be used in any materials for which it is possible to qualify welding procedures, welders, and welding operators. Dimensional and other requirements are detailed.

Threaded joints - major consideration here is tightness, especially for flammable or toxic liquids, and it is suggested that threaded joints be avoided where severe crevice corrosion or erosion may occur.

Caulked joints - may be used only for water and drainage service.

Brazed and soldered joints - may not be used in systems containing flammable or toxic fluids.

Proprietary joints - may be used provided adequate provision is made to prevent separation and provided a prototype joint has been subjected to performance tests to determine the safety under simulated service conditions.

ANSI Standard B31.4 permits fewer types of joints than B31.3: only welded, threaded, and patented joints. The requirements of B31.4 for making these joints are qualitatively similar to those of B31.3.

6.2.4 Piping Supports

The importance of piping supports arises from the many different sources of loads on piping systems and the corresponding need to limit the

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6.2.4 Piping Supports

The importance of piping supports arises from the many different sources of loads on piping systems and the corresponding need to limit the motions and stresses in the piping system. The conditions and influences which must be taken into account in designing piping systems and their supports and restraints include the following:

- Design pressure and temperature
- Ambient influences, e.g. cooling of a gas or vapor or increased pressure due to heating of static fluid in a piping system
- Dynamic effects, including impact forces such as hydraulic shock or slugging, wind, earthquake, vibration and discharge reactions.
- Weight Effects, including weight of piping and weight of medium transported
- Thermal expansion and contraction effects .

The design of the piping, including the supports, must be made with the objectives of preventing the following:

- Excessive stresses in the pipe
- Leakage at joints
- Excessive forces or moments on connected equipment
- Excessive stresses in the supports
- Resonance with imposed vibrations
- Excessive interference with thermal expansion and contraction
- Unintentional disengagement of piping from supports
- Excessive sag in piping requiring drainage slope.

There are specifications for supports regarding materials to be used, threads, means of attachment to pipe, etc; for details on these, see Section 321 of ANSI B31.3 and Section 421 of ANSI B31.4.

6.2.5 Valves

In ANSI B31.3, valves must comply with specifications listed in Appendix A, Allowable Stresses in Tension for Materials, and in Table 326.1, Dimensional Standards. Special valves not specifically covered by standards listed in Table 326.1 may be used provided the designs meet Code requirements of Section 304, Pressure Design of Components.

Similarly, in ANSI B31.4, standards and specifications for valves are covered as follows:

Steel valves	Tables 423.1, Material Standards and 426.1, Dimensional Standards and Paragraph 3.2 of API Std 6D covering certain cast, malleable, or wrought iron parts.
Cast Iron valves	Tables 423.1 and 426.1 for pressures not greater than 250 psi
Special valves	not listed in Tables 423.1 and 426.1 shall be permitted provided that their design is of at least equal strength and tightness and will meet same test requirements as covered in B31.4.

Working pressure ratings of steel parts of steel valves are applicable within temperature limitations of -20 F to 250 F.

6.2.6 Inspection and Testing

In ANSI B31.3 a distinction is made between inspection and examination:

- "Examination" or "examiner" refer to quality control functions performed by personnel in the employ of the manufacturer, fabricator, or erector
- "Inspection" or "inspector" applies to functions performed by or for the owner to determine that the appropriate "examination" has been done and that the piping therefore meets Code requirements.

This distinction is not made in B31.4. However, the quality control methods to be used are similar in the two codes. Generally, nondestructive examination methods are specified, and include: visual, magnetic particle, liquid penetrant, radiographic, and ultrasonic examination methods. B31.4 also includes the possibility of destructive testing of welds where required by the inspector. All of the methods are covered by sections of the Standards themselves, or by other codes indicated. See Section 336 of B31.3 and Section 436 of B31.4 for details of examination requirements.

ANSI B31.3 requires that installed piping be pressure tested before initial operation. There is no exception from this requirement for hazardous liquids. Internal pressure piping shall be hydrostatically tested at a pressure at least 1½ times the design pressure, unless the design conditions will result in stressing of some parts at such a pressure beyond 90 percent of minimum specified yield strength (MSYS) at test temperature. In the latter case, the hydrostatic test pressure shall be lowered to a value such that the stress does not exceed 90 percent of MSYS. Also, if the design temperature is above 650 F, the minimum test pressure shall be as calcualted by Equation 20 of Section 337. If hydrostatic testing is not considered practical, then pneumatic tests or other special alternate tests may be used as specified in Sections 337.4.3 or 337.5.

ANSI B31.4 requires that after construction, all liquid petroleum transportation piping systems be tested, specifically that systems to be operated at a hoop stress of more than 20 percent of MSYS shall be hydrostatically tested to a pressure not less than 1.25 times the design pressure for not less than 8 hours. Systems to be operated at less than 20 percent of MSYS may be tested pneumatically at 100 psig, mainly to locate leaks. See Section 437 of B31.4 for full details on testing.

6.3 Agitator Stuffing Boxes

Stuffing boxes or seals are used to avoid the flow of fluids from a tank to the environment through the space between a rotating shaft and its housing. In some cases, agitators may be used on tanks containing hazardous wastes. If such wastes are volatile and either toxic or ignitable, then some major operating troubles may occur involving leaks unless the agitator stuffing box is well designed. Where agitators are used on tanks containing volatile hazardous materials, the permit writer should assure himself that agitator stuffing boxes are not likely to become a source of significant leaks and that proper design procedures have been used. Thus, the permit writer should request information from the applicant regarding the engineering details used in the design of the stuffing box.

Two types of stuffing boxes are in common use—mechanical seals and stuffing boxes packed with materials frequently used for gaskets. Proper selection of materials of construction is essential for both types of stuffing boxes. Some discussion of materials of construction for seals is presented in Appendix B, Section B.4.1, titled "Gaskets". (The full reference to a duscussion about seals in Mark's Standard Handbook for Mechanical Engineers is also presented in Section B.4.1.)

CHAPTER CONTENTS

7.0 TANK ANCILLARIES: FOUNDATIONS, SUPPORTS, INSULATION AND GROUNDING

- 7.1 Foundations
  - 7.1.1 Sites Requiring Special Considerations
  - 7.1.2 Methods to Correst Subgrades
  - 7.1.3 Nonearthen Foundations
  - 7.1.4 Earthen Foundations
  - 7.1.5 Tank Grades
- 7.2 Structural Tank Supports
- 7.3 Thermal Insulation
- 7.4 Electrical Grounding

7.0 TANK ANCILLARIES: FOUNDATIONS, SUPPORTS, INSULATION, AND GROUNDING

Chapter 5.0 dealt with instrumentation and control systems for safe tank operation and Chapter 6.0 dealt with tank system hardware such as pumps and piping. This Chapter 7.0 deals with other tank ancillaries including foundations, supports, thermal insulation, and electrical grounding.

Title 40 CFR 264.191(a) requires that "The Regional Administrator will review the design of the tanks, including the foundation, [and] structural support, . . .".

7.1 Foundations

Specific standards for the design of foundations are not available probably because of the complexity of the subject and the numerous solutions available to the engineer for solving varying site conditions. Appendix C of API 620 and Appendix D of API 650 provide some general guidance about foundations.

Because foundation standards are not available, the permit writer must rely on information provided by the applicant to review the foundation design. The most important aspect in such a review is that the design must have been performed by qualified personnel such as a geologist and a foundation engineer.

Specific design details made available to the permit writer should include the following:

- Soil-bearing tests or other information defining conservative soil-bearing values.
- Computation of the design loading to be imposed by the tank and its contents when full.
- Design details where applicable of unsuitable soil to be removed; fill sand, gravel, or crushed stone to be used (sometimes to avoid corrosion to the bottom of the tank); compaction of the fill; elevation of the foundation above grade, use of a berm; footing depth and width; use of ACI Standard 318 for reinforced concrete; ring wall design; and the amount of crown to be used under the tank.

- In some cases for API 620 tanks, settlement measurements during the hydrostatic test may be available.

The following information is primarily an abstract taken from API Standard 650 for atmospheric-pressure storage tanks.

7.1.1 Sites Requiring Special Considerations

When facilities are constructed at the following types of sites, special structural considerations are required.

- Hillside sites, where the depth of required fill is variable
- Sites on swampy or filled ground, where compressible vegetation is near the surface, or where unstable or corrosive materials may have been used
- Sites over layers of plastic clay, which may settle excessively
- Sites adjacent to water courses or deep excavations, where lateral stability of the ground is questionable
- Sites immediately adjacent to heavy structures, which distribute some of their load to the subsoil under the tank site
- Sites where tanks may be exposed to floodwaters.

7.1.2 Methods to Correct Subgrades

If the subgrade is weak or inadequate to carry the load of a full tank, construction under the tank bottom is necessary. One or more of the following general methods may be used:

- Remove the objectionable material and replace with other suitable material
- Compact soft material with short piles or by preloading with an overburden of earth or other material and by assuring proper drainage of the overburden
- Compact the soft material by draining off the water
- Stabilize the soft material by chemical methods or injection of cement grout
- Drive load-bearing piles or construct foundation piers to serve as a reinforced slab on which to distribute the load of the tank.

Fill material used to replace objectionable materials and to build a suitable base (e.g., to build up the grade to a suitable height) should be of high quality. It should be free of vegetation and organic matter and should not contain substances, such as cinders, that could cause corrosion of the tank bottom. The fill should be thoroughly compacted.

7.1.3 Nonearthen Foundations

When the properties of the underlying soil are corrosive to the tank or inadequate to support the load of a full tank, a nonearthen foundation is needed. Piles may be used under the foundation for support. Piles can be made of steel, reinforced concrete, or concrete-filled steel shells. Appropriate foundations are especially important when the facility location is in an earthquake zone, a marshy area, or an otherwise unstable area.

7.1.4 Earthen Foundations

If subsurface conditions indicate that it is unnecessary to construct a substructure to support the tank, suitable foundations may be constructed from earthen materials. The performance requirements for an earthen foundation are identical to those associated with artificial material foundations. Specifically, the foundation should:

- Provide a stable plane for the support of the tank
- Limit overall settlement of the tank grade to values compatible with allowance provided in the design for connecting piping and
- Provide adequate drainage.

7.1.5 Tank Grades

The tank should be constructed above the surface of the surrounding ground. This will provide for suitable drainage, help keep the bottom of the tank dry, and even if some settlement occurs, elevate the tank above the surrounding surface.

It is suggested that the top 3 to 4 inches of the finished grade consist of clean sand, gravel, crushed stone, or some similar inert material that can be readily shaped to the proper contour. During construction, the movement of equipment and materials across the grade will mar the surface of the softer materials. These irregularities should be corrected before the bottom plates are in place for welding.

To preserve the contour during construction and to protect the tank bottom against ground moisture, the finished grade may be oiled or stabilized in some other manner. Caution should be exercised in assuring that the quantity or kind of material used for this purpose does not create welding difficulties or a risk of galvanic corrosion.

Normally, the finished tank foundation grade should be crowned from the outer periphery to the center. A slope of 1 inch in 10 feet is suggested as a minimum. Because the amount of crown will affect the lengths of roof-support columns, it is essential that the tank manufacturer be fully informed of the slope in advance. Some settlement of this crown should be anticipated upon filling and operating the tank.

7.2 Structural Tank Supports

The design of structural supports for tanks is another area for which there are no specific design standards. However, Appendix D of API Standard 620 does provide some general guidance. Similar to the situation for foundations, the permit writer must rely on information provided by the applicant.

- The most important aspect of the permit review is that the structural design must have been performed by qualified personnel (or organization).

If the vendor of the tank was made aware of the amount and type of material to be stored in the tank and was made responsible for the design and fabrication of the structural supports, then the permit writer need not be overly concerned, assuming that the tank vendor is generally recognized as being reputable.

In other cases, it is suggested that the permit writer review Appendix D of API Standard 620; the permit writer should also anticipate the need for some moderate engineering analysis during both the completeness and technical review phases of the permitting process. Nevertheless, the applicant must provide full disclosure of design computations and drawings.

7.3 Thermal Insulation

There is no regulatory requirements in Title 40 CFR regarding hazardous waste storage and treatment that the Regional Administrator review the thermal insulation on tanks. Furthermore, thermal insulation on tanks will seldom be required to make the process operable in such facilities. Nevertheless, the permit writer may become concerned about personnel protection against burns from tanks containing unusually hot materials. There is no code specifying that tanks with a surface temperature exceeding some specific value should be thermally insulated. If the temperature is about 120 F (50 C), then the human hand can be held continuously against steel with some discomfort. However, some burning is possible if the temperature exceeds about 175 F (80 C); therefore, thermal insulation might be suggested if the contents of a tank are likely to exceed this latter temperature and contact of personnel with the tank is possible.

7.4 Electrical Grounding

When fluids are pumped at sufficiently high velocities through piping or orifices, static electricity is likely to be formed. In the presence of a flammable mixture, this static electricity may cause a spark, and a subsequent explosion or fire. However, static electricity may be dissipated by "grounding" it back to a steel tank containing the liquid. The permit writer should become most concerned if a metal pipe pumping flammable (ignitable) liquids discharges the fluid near the top of the tank and if the pipe is not electrically "grounded" to the shell of a steel tank. (The word grounded when used above may be viewed as a misnomer because the grounding is not to the earth, but rather to the shell of the tank.) In the situation above, the problem may be remedied by providing such grounding by a conductive (non-corrosive) metal. However, an alternative remedy must be used when the pipe or tank is non-metallic; the most appropriate remedy may be to assure that the liquid enters near the bottom of the tank. The National Fire Proteciton Association (NFPA) Code 77, "Recommended Practices on Static Electricity", presents a full discussion of the subject with further elaboration on the scope of concern and on potential remedies.

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8.0 INSPECTIONS

A tank and its auxiliary equipment must be properly inspected on a routine basis to ensure that the tank system is in good working order primarily to prevent uncontrolled discharges of hazardous wastes to the environment. Inspections may result in the conclusion that the tank should be derated or no longer used for service if the tank is not economically repairable. The regulations do not require secondary containment for tanks and, therefore, any leak or other failure is an extremely hazardous situation to be avoided. Regular inspections using effective procedures are the only mechanism available to forecast the possibility of tank failure.

The permit writer is responsible for specifying the minimum allowable shell thickness and the frequency of inspections. According to regulation 40 CFR 264.194(b), the applicant is required to develop a procedure to assess the condition of its tanks. The permit writer should be concerned that the procedure proposed by the applicant will detect any defect in the tank before the defect's depth can violate the minimum shell thickness. The maintenance of a minimum shell thickness for a tank may be viewed as being similar to the requirement for secondary containment.

In general, this chapter 8.0 is written with metal tanks in mind. Fiberglass-reinforced plastic tanks are somewhat different in that they often fail by different mechanisms of deterioration than metal tanks. Section 4.2 "Fiberglass-Reinforced Plastic Tanks" presents further information about plastic tanks, including a discussion about minimum shell thickness equivalent (Section 4.2.3) and frequency of inspection (Section 4.2.4).

Stress corrosion around weld seams, corrosion at the liquid-vapor interface, oxidative corrosion due to the presence of oxygen (from the air) in the vapor space of vented atmospheric tanks, caustic embrittlement, and hydrogen blistering are all types of corrosion which may occur in a non-uniform way on the surface of the metal. However, careful visual inspection for these types of corrosion will usually be adequate to detect the possibility of defects which would require more detailed examination. However, pitting is another form of corrosion that in some cases may not be readily detected through visual inpsection. Furthermore, the nature of corrosion by pitting is such that once the pit has been formed, the rate of corrosion may be accelerated.

Pitting may occur where the liquid is locally stagnant, and a concentration gradient of electrolyte may develope that, in turn, develops a small electrolytic cell, causing localized corrosion in the form of a pit. Tank bottoms, weld seams and dead pockets are the tank locations in which pitting often occurs. Liquid streams containing chlorides are notorious for the possibility of pit corrosion, as are liquid streams containing sludges which may settle to the tank bottom and, thus, form a dead pocket. Pitting has been observed directly below openings on tanks storing crude petroleum due to rainwater settling to the bottom and forming electrolytic solutions from the salts contained in the petroleum. In some cases, the pits formed in the metal may not appear to be pits upon causual inspection because they have become filled with corrosion products and sludge.

Thus, the permit writer should

- Require that the applicant provide information on the expected corrosion rate of the liquid on the tank material and the likelihood of pitting and other forms of non-uniform corrosion.
- Insist that the applicant provide information supporting the conclusion that inspections will be performed by qualified personnel using procedures that would detect both uniform and non-uniform corrosion of all types.

All permit writers unfamiliar with tank inspection procedures should read the American Petroleum Institute Guide for Inspection of Refinery Equipment, Chapter XIII,"Atmospheric and Low-Pressure Storage Tanks". Particular attention should be given to sections 1302 through 1306.03.

A list of tools required for tank inspections is presented in Section 1304 of the API Inspection Guide as Tables 1 and 2. (Also see section 8.5 of this manual.) Relatively detailed explanations on how many of the common tools are used in inspection are presented in the text.

It should be noted that in the API Guide relatively heavy reliance is made initially on visual techniques of tank inspection to detect evidence of non-uniform corrosion; however, upon detection of potential defects, more sophisticated methods are used to verify and determine the extent of the defect. For example, pits may be measured by depth gage; thicknesses determined by calipers or, in some cases, drilling a hole, which is then measured by hook gage and plugged; cracks measured by penetrant dye or magnetic particle techniques and leaks verified by a vacuum-box tester with soapy water. In some cases test specimens may be removed from some portion of the tank (frequently the bottom) for detailed examination. Some of the methods mentioned above are destructive in nature. Ultrasonic thickness detectors are commonly used to measure for changes in thickness due to uniform corrosion and to detect other flaws. Ultrasonic inspection has the advantage that measurements may be made from the exterior of the tank.

8.1 Evaluation of Inspection Plan

The inspection plan proposed in a permit application should clearly describe all the procedures required to comply with the regulations in 40 CFR 264.194. In brief outline format the required inspections are:

(1) Overfilling control equipment, once per day
(2) Data on tank operating conditions, once per day
(3) Level in uncovered tanks, once per day
(4) Above-ground (external) portions of the tank to detect corrosion and leaks, once per week
(5) Area around tank to detect signs of leaks, once per week
(6) Detailed external and internal assessment of tank condition adequate to detect cracks, corrosion, erosion, or wall thinning that may lead to leaks or inadequate strength according to a predetermined schedule.

The daily inspection of (1) overfilling control equipment is covered in greater detail in Section 8.4.3.

The daily inspection of (2) data on tank operating conditions such as pressures, temperatures, and liquid levels that should be recorded on operator's log sheets or on charts from recording instruments, should be part of the normal operating procedure. Operators and foremen, should be trained about the range of values that are acceptable practice and to notify supervision when such values have been violated. Further discussion of this latter type of inspection is not presented here.

The daily inspection of the (3) level of wastes in uncovered tanks to assure adequate freeboard to prevent overtopping due to winds or precipitation is reasonably self-explanatory. Of course, specific standards should be established to guide operators on the maximum levels that can be allowed without problems. It would be prudent for the applicant to initially set very conservative maximum levels and then base any changes on observations made on windy days. The minimum freeboard that should be allowed is a function of many variables, including maximum wind velocity, nearby topography and buildings, windscreens, wind direction, tank diameter, liquid viscosity, and maximum 24-hour (or longer) rainfall. This inspection is to be made visually and not by reliance on instruments and other indirect means of data acquisition. Further discussion on this inspection is not presented herein.

The weekly inspection of (5) the area around tanks to detect signs of leaks such as wet spots, dried residues, dead vegetation, or discolored spots does not require further explanation.

The remainder of this section presents information to guide the permit writer on the inspection of

(1) Over-filling control equipment, daily

(4) Above-ground (external) tank inspection for leaks and corrosion, weekly

(5) Detailed external and internal assessment of tank condition

8.2 Weekly Above-Ground External Tank Inspection

Regulation 264.194(a)(4) requires inspection of "the construction materials of the above-ground portions of the tank, at least weekly, to detect corrosion or erosion and leaking of fixtures and seams". The intent of this regulation should be viewed more as an attempt to detect leaks or the potential for imminent leaks, and less as a detailed assessment of the condition of the tanks. Items to be assessed during this inspection include:

- Erosion around and cracks in the foundation and pads
- Corrosion, leaks, or distortion around nozzles and piping connected to the tank
- Evidence of deterioration of protective coatings by the appearance of corrosion, discoloration, blisters or other film lifting.
- Evidence of corrosion of tank tops or roofs
- Proper functioning of roof seals (if any) and roof drains (if any)
- Corrosion, discoloration, leaks, cracks, bulges, and buckles of seams and plates of the tank wall and bottom (if accessible).

If the external portions of the tank are covered with insulation, then careful inspection of the insulation for leaks or evidence of leaks such as discoloration would be the appropriate procedure.

Until potential defects are observed, this inspection is strictly a visual inspection. However, upon detection of a defect, more sophisticated inspection procedures would be appropriate. Of course, if a leak is detected, further leakage should be stopped and the tank promptly repaired or replaced.

8.3 Detailed Assessment of Tank Condition, (as scheduled)

The detailed assessment of tank condition proceeds in two stages. the external inspection and the internal inspection, as follow:

8.3.1 External Inspection

Many elements of the external tank inspection may be made while the tank is in service; for example, ultrasonic examination of the average shell thickness. (However, the measurement of average shell thickness is listed as part of the internal inspection procedure in this document.) A detailed description of the external tank inspection procedure is presented as section 1304.02 of the API Guide of Inspection of Refinery Equipment, Chapter XIII, "Atmospheric and Low-Pressure Storage Tanks" and is not repeated herein. However, a checklist of the items to be investigated and what to look for has been presented as Table 8-1 based on the API Guide. Some external inspection procedures should not be performed until the tank has been shut down and emptied.

8.3.2 Internal Inspection

The internal inspection described by the applicant should take place in at least two major phases--emptying the tank and the inspection. According to 40 CFR 264.184(b), the applicant must establish procedures for emptying the tank to allow entry and inspection of the interior. Although the intent of this regulation is not made explicit, the permit writer should be concerned with safety of personnel, avoidance of spills to the environment, and other hazardous conditions. A checklist of items with which to be concerned is presented in Table 8.2. The checklist includes consideration of lined and fiberglass-reinforced plastic (FRP) tanks. (Further information about FRP tanks is presented in Section 4.2.3.)

8.4 Inspection of Auxiliary Equipment

Common auxiliary equipment and system components attached to tanks used for hazardous waste include pipes, valves, and fittings; pumps and compressors; and instruments, control equipment, and electrical systems. Inspection of these are discussed in the following sections.

TABLE 8-1. CHECKLIST OF TANK EXTERNAL-INSPECTION POINTS

A. Tank In Service

- (1) Ladders, Stairways, Platforms and Walkways
  - worn or broken parts and treads
  - corroding parts
  - cracked or spalled concrete pedestals
  - low spots where water can collect
  - loose rivets and bolts
- (2) Foundations
  - erosion
  - uneven settlement
  - cracks and spalling in concrete pads, base rings, and piers
  - deterioration of water seal between tank bottom and the foundation
  - distortion of anchor bolts
- (3) Pipe Connections
  - external corrosion
  - cracks and distortion
- (4) Electrical Grounds
  - corrosion where enters ground
  - resistance
- (5) Protective Coatings
  - rust spots, blisters, and film lifting
- (6) Tank Walls
  - corrosion (underground and under insulation in particular)
  - discoloration of paint surface
  - cracks at nozzle connections, in welded seams, and at the metal ligament between rivets
  - cracks, buckles, and bulges
  - tightness of bolts or rivets, if applicable
- (7) Tank Roofs
  - malfunctioning of seals
  - blockage or breakage of water drains on roofs
  - corrosion

TABLE 8.1. (Continued)

- (8) Overfilling Control
    - malfunction of controls
    - insufficient freeboard

B. Tank Out of Service

- (1) Tank Bottoms (only if appropriate)
    - tunneling method
- (2) Pipe Connections
    - hammering
    - at point of entrance at soil line
- (3) Tank roofs, pontoons, double decks, seals, and purlins
    - hammering
    - visual
    - leaks
- (4) Valves and Valve Seats
    - visual
- (5) Auxiliaries
    - vents for plugging, breather valves for seating
    - liquid-level controls for cracks and corrosion
    - pressure gages for plugging and accuracy.

TABLE 8-2. CHECKLIST FOR TANK INTERNAL INSPECTION (TANK OUT OF SERVICE)

A. Tank Emptying and Preparation For Inspection

- avoidance of spills
- avoidance of hazardous conditions (reaction, ignition, or toxic exposure)
- use of appropriate materials of construction for any temporary storage containers (or tanks) and connecting systems
- cleaning and ventilation procedure
- complete disconnection or blanking off of all connecting piping
- air quality check
- adequate lighting
- personal safety equipment as appropriate (clothing and respiratory)
- Standby equipment and services readily available

B. Interior Inspection of Solid Steel Tanks

(1) Roof and Structural Supports (visual first for safety)

- no hazard of falling objects
- corrosion

(2) Roof and Structural Supports (more rigorous)

- loss of metal thickness
- cracks, leaks at welds
- cracks at nozzle connections
- malfunction of floating roof seals
- water drain system deterioration
- hammering

(3) Tank Shell

- cracks at seams
- corrosion of vapor space and liquid-level line
- cracking of plate joints
- cracking of nozzle connection joints
- loss of metal thickness

TABLE 8-2. (CONTINUED)

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(4) Tank Bottom

- hammer testing
- corrosion pits
- sprung or cracked seams
- rivets for tightness and corrosion
- depressions in the bottom areas around or under roof supports and pipe supports
- bottom thickness
- unevenness of the bottom
- sample coupons, if appropriate

C. Interior Inspection of Lined Steel Tanks

NOTE: Some of the procedures and locations to inspect noted in section B for solid steel tanks above are equally applicable to lined tanks. Tanks may be lined with alloy steel, lead, rubber, glass, coatings, and concrete.

- general condition of lining (holes, cracks, gaps, corrosion, erosion, swelling, hardness, loss of thickness)
- proper positioning of liner
- bulges, blistering, or spalling
- spark testing with rubber, glass, and organic type coatings
- ultrasonic examination of steel outer shell thickness is possible if any deterioration is suspected.

D. Interior Inspection of Fiberglass Reinforced Plastic Tanks

- hardness test of any test specimens exposed to liquid in the tank
- indentations, cracks, exposed fibers, crazing, checking, lack of surface resin, and delamination
- if sufficiently translucent, porosity, air or other bubbles, other inclusions, and thin areas
- ultrasonic examination of laminate thickness is possible if any deterioration is suspected in the polyester matrix.

8.4.1 Pipes, Valves, and Fittings

Inspections of pipes, valves, and fittings are usually conducted to note any leaks, cracks, corrosion, or losses in metal thickness owing to external or internal deterioration. The internals of these equipment parts are subject to erosion or wear because of the effects of high liquid turbulence or velocity. Areas around pipe bends, elbows, tees, and other restrictions, such as orifice plates and throttling valves, are particularly subject to erosion.

Visual inspection techniques include checking for leaks, misalignment, unsound piping supports, vibration or swaying, external corrosion, accumulations of corrosive liquids, and indications of pipe fouling. Thickness measurements while the pipes are in operation can be taken utilizing ultrasonic or radiographic techniques.

If the tank is out of service or if a line can be valved off, with proper safety precautions piping can be opened at various places by removing a valve or fitting or by springing the pipe apart at flanged locations to permit internal visual inspection. A flashlight or extension light is needed in most cases and a probe-type instrument, such as a borescope, or a mirror and light will permit a more detailed view. If corrosion or erosion conditions are noted visually for some parts, radiographic or ultrasonic techniques can be used to inspect the entire length of pipe, if inaccessible to visual examination. Replacement may be more economical than such techniques in some cases if the entire piping run is suspect. Gaskets should often be replaced if the line is broken at flanges.

A brief checklist for inspection of piping, valves, and fittings is presented as Table 8-3.

TABLE 8-3. CHECKLIST FOR INSPECTION OF PIPING, VALVES, AND FITTINGS

- Leaks
- Cracks or corrosion
- Metal thickness (by hammering or caliper)
- Metal thickness (by ultrasonics, radiation, or eddy current
- Gasket condition
- Alignment, distortion, and swaying
- Valve seats
- Pipe rack supports or hangers
- Vibration
- Erosion

Piping systems that cannot be inspected visually are frequently pressure tested. They include:

- Underground and other inaccessible piping
- Complicated manifold systems
- Small pipe and tubing systems
- All systems after a chemical cleaning operation.

The most used media for pressure tests is water. In this type of test the water is pumped into the pipe such that the quantity of gas in the pipe is minimal. When the pressure has reached the test pressure, the system is valved off but with a pressure gage on the closed system. Small leaks of the incompressible water results in a rapid and significant drop in pressure and, thus, the probability of a leak is established. Use of compressible or condensible gases such as steam, air, carbon dioxide, and so forth is generally less reliable; more reliance must be placed on hearing the sound of escaping gas or otherwise detecting leaks.

8.4.2 Pumps and Compressors

Mechanical wear is the predominant cause of deterioration of pumping and compression equipment, although erosion and corrosion are also responsible for an appreciable amount of deterioration. Other deteriorating factors include improper operating conditions, piping stresses, cavitation, and foundation deterioration causing misalignment or vibrations.

Since vibration can rapidly deteriorate a pump or compressor, periodic examination of the vibration level should be made using an electronic vibration meter. Inspection of all assembly bolts, gaskets, cover plates, and flanges should be conducted to detect leaks and cracks as a result of vibration or abnormal operating conditions.

A brief checklist for the visual inspection of pumps and compressors is presented as Table 8-4.

TABLE 8-4. CHECKLIST FOR VISUAL INSPECTION OF PUMPS AND COMPRESSORS

- Misalignment
- Foundation cracks and uneven settling
- Missing or broken anchor bolts
- Leaky piping connections
- Excessive vibrations and noise
- Deteriorating insulation
- Depleted lubrication oil reservoir
- Missing safety equipment such as a pump coupling guard
- Burning odor or smoke
- Excessive dirt
- Excessive corrosion
- Leaks and cracks at assembly bolts, gaskets coverplates, and flanges

Two pumps are often installed in parallel such that one pump may be shut down while the other does all the required pumping. Thus, one pump may undergo a complete internal inspection or replacement while the system remains in operation.

8.4.3 Instruments, Control Equipment, and Electrical Systems

Instruments, control equipment, and electrical systems must be inspected at the minimum required frequencies given in 40 CFR 265.194 and section 8.5 of this manual to ensure that they are in good working order. Level controls, emergency shut-off devices, and alarms are among the most important devices for fail-proof tank operation. Flow rate controls, temperature gauges, pressure gauges, and analyzers are among the less important devices.

A brief checklist of what should be inspected regarding the instruments, control equipment, and electrical systems is presented in Table 8-5.

TABLE 8-5. CHECKLIST FOR INSPECTION OF INSTRUMENTS AND CONTROL SYSTEMS

- Instruments
- Transmission systems
- Power supplies
- Seals
- Panels and enclosures
- Electrical Equipment
- Insulation
- Operating mechanisms (moving parts)
- Insulating and lubricating oils
- Protective relays
- Bearings
- Batteries
- Connectors
- Rectifiers

The visual inspection should specifically watch out for any deteriorating effects of the following on electrical systems:

- Heat
- Dirt
- Moisture
- Chemical attack.

The instruments and controls must be calibrated by qualified personnel as per the methodology and frequency recommended by the vendors.

Inspection of the data gathered by instruments should be included as an integral part of the overall inspection plan for instruments, control equipment, and electrical systems. Any unexpected discontinuities or abnormal peaks in data charts or data logs may indicate that there is some cause for concern in the control systems.

8.5 Inspection Tools and Procedures

When visual inspection suggests that tools are needed for a more detailed inspection, simple hand tools may be used as an initial aid. Tools such as a scraper, digger, flange spreader, knives, paint or crayon, portable lights, and rules are indispensable for visual inspection. Additional tools such as hammers, mirrors, magnifiers, magnets, and internal visual scopes are also helpful.

The mechanical measuring tools include calipers, micrometers, scales and tapes, wire gauges, level and plumb bob and line, depth gage, hook gage, square, and straightedge.

Approved destructive examination methods include drilling a hole through the tank wall or bottom, then using a hook gage to measure thickness, tapping the hole, and inserting a threaded plug. Another method is to cut large (12 inch by 12 inch) test specimens from the tank for detailed examinations; this is often performed for tanks where the bottom cannot be externally inspected. A trepanning saw may be used to remove a portion of a weld from the tank for examination.

Brief descriptions of other inspection tools and methods follow:

8.5.1 Hammering Method

Full blows of the hammer are used and the sound, feel, and imprint of the hammer head noted. Where corrosion or erosion is significant, the sound will be dull, the feel soft, and a dent or hole likely. Hammering is frequently performed on tank roofs, bottoms, and on floating roof components.

8.5.2 Penetrant-Dye Method

Penetrant dyes are often used to define surface cracks on a tank that would not be verified by a visual inspection. The penetrant is applied by either brushing or spraying to a surface carefully cleaned (often by sandblasting), dried, and then the excess is removed. After a few minutes of contact to allow penetration into the crack, a chemical developer is then applied to the surface. The dye stains the developer and exposes the extent and size (but not the depth) of any defects.

8.5.3 Magnetic-Particle Method

The magnetic-particle method is also used to define surface cracks on tanks similar to the penetrant-dye method. The surface must also be carefully cleaned and then iron particles are sprinkled on the surface. A magnetic field is then imposed near the particles either by a permanent magnet (especially if flammable materials are stored nearby) or an electromagnetic device and the particles arrange themselves along the crack and particularly near the ends of the crack. The magnetic field should be imposed in two directions to assure there is no crack or to identify two or more cracks running in different directions. No indication is given about the depth of the crack. This method may be used only on tanks constructed of magnetic materials.

8.5.4 Radiographic Method

Welds are often radiographed during tank fabrication to detect thickness and flaws of the welds. This method may also be used to determine thickness of tank plates. The device may use either X-rays or gamma radiation and must be calibrated prior to use. It is similar in many respects to the X-ray machines used for dental and medical purposes.

8.5.5 Ultrasonic Method

Ultrasonic instruments can be used to measure the tank's thickness and determine the location, size, and nature of defects. They can be used while the tank is in operation as only the outside of the tank needs to be contacted with the device. Two types of ultrasonic instruments, the resonance and the pulse type, are most commonly used for tanks. The pulse type utilizes electric pulses and transforms them into pulses of ultrasonic waves. The waves travel through the metal until they reach a reflecting surface. The waves then are reflected back, converted to electrical pulses, and show up on a time-base line of an oscilloscope. The instrument is calibrated by using a material of known thickness. Therefore, the time interval between the pulses corresponds to a certain thickness.

8.5.6 Vacuum-Box Method

The vacuum box is an open box in which the lips of the open side are covered with a sponge rubber gasket, and the opposite side is glass. A vacuum gauge and air siphon connection are installed on the box. The seam of the tank shell where a leak is suspected is first wetted with a soap solution, then the vacuum box is pressed tightly over the seam. The foam-rubber gasket forms a seal, and a vacuum is achieved inside the box by the air siphon. If a leak exists, bubbles will form inside the box and can be seen through the glass.

8.6 Frequency of Tank Inspection

There are several regulatory requirements regarding tank inspections and, in the case of the detailed assessment of tank condition, other practical considerations.

8.6.1 Regulatory Requirements

The frequency of performing some types of tank inspections is presented in 40 CFR 264.19 and is summarized in Table 8-6.

TABLE 8-6. MANDATED INSPECTION FREQUENCIES

At Least Once Per Normal Operating Day
- Overfilling control equipment
- Data on tank operating conditions
- Level in uncovered tanks

At Least Once Per Week
- Above-ground external portions of tank
- Area surrounding tank

Although the permit applicant is required to present a schedule for the detailed assessment of tank condition, the permit writer is ultimately responsible for specifying the appropriate schedule in the permit issued to the applicant.

Title 40 CFR 264.15(b) states that the frequency of inspection for other items should be based on the rate of possible deterioration of the equipment and the probability of an environmental or human health incident if the deterioration or malfunction goes undetected. Part 264.194(b) requirements for periodic comprehensive tank inspections specify the following additional factors to be used in determining inspection intervals:

- Material of construction of tank
- Type of erosion or corrosion protection used
- Characteristics of waste being stored
- Rate of corrosion or erosion observed during previous inspections.

8.6.2 Practical Considerations

The detailed tank assessment is often a costly requirement for the operator of a hazardous waste storage facility because the tank must be shut down, blocked off, emptied, cleaned, and undergo detailed examination by qualified personnel. Unless the operator has spare tanks, shutdown of the tank may temporarily also necessitate closure of the facility. Adequate tank cleaning for personnel safety may also be a costly step in terms of both elapsed time and other dollar costs. Furthermore, there is always some potential for residual hazardous materials to remain in nozzles or piping associated with the tank. Thus, tank inspections must be frequent enough to avoid leaks and spills but should not become necessarily burdensome to the operator of the facility.

In cases where the corrosion rate data are known at storage temperature for the specific material of construction of the tank with the specific liquid to be stored in the tank and only uniform corrosion has been experienced in prior applications, the expected service life of the tank can be realistically estimated, which can then be used to establish a reasonable inspection schedule. During the initial years, scheduled inspections at 20, 40, and 60 percent of the tank's service life would be reasonable frequency. For example, a tank with an expected service life of 25 years might initially be subjected to a comprehensive inspection every 5 years to establish the actual rate of corrosion or deterioration. However, after shell thickness measurements were made and the existence of any non-uniform corrosion noted, the estimated service life could be re-estimated and the inspection frequency increased if necessary as the tank approaches the end of its service life and the probability of leaks or ruptures increases; for example, the inspection frequency could be increased to every 1 to 2 years.

If non-uniform corrosion has been experienced by a material of construction with the liquid to be contained, much more frequent initial inspections should be scheduled. Pitting and crevice corrosion are particularly obnoxious because not only does there often seem to be an induction period with little observable physical damage, but also the corrosion accelerates once the pit or crevice is formed due to formation of a larger electrolytic cell. Materials subject to pitting or crevice corrosion should normally not be selected unless an economic analysis clearly indicates a preference toward frequent inspections rather than to a more costly material of construction.

8.6.2.1 More Frequent Detailed External Inspections. In some cases where any form of non-uniform corrosion is not expected, the owner or operator may prefer to conduct more frequent comprehensive external inspections of the tank to avoid the expense of frequent internal inspections, providing all portions of the tank are accessible, including the bottom. In the example cited above, the owner-operator could initially conduct annual external inspections, which include intensive measurements of tank shell thickness (i.e, one measurement per square yard of surface area) and reduce the frequency of internal inspections to once every 7 years. As the condition of the tank deteriorates, however, the frequency of internal inspections should increase to every 1 or 2 years.

8.6.2.2 Immersed Test Coupons. In cases where few corrosion data are available or proper tank inspection would be very costly, test specimens (coupons) of material literally from the same heat (or batch) of the metal used to construct the tank may be immersed in the liquid, with some coupons allowed to rest on the bottom of the tank. These test coupons may be stressed by bending and welding to form crevices to simulate problem areas in the tank. Samples can be withdrawn annually and measurements made of thickness and observations made about stress, crevice, and pitting corrosion. The data collected could then be used to suggest an appropriate inspection schedule; of course, an inspection schedule should be established that requires greater frequency than that projected by the data from the coupons.

In the case where a used tank has been installed and no coupons may be taken from the specific heat (or batch) of material from which the steel plate was manufactured, and the specific type of material used is not certain, a small sample of the tank metal may be removed and analyzed by emission spectroscopy to classify the metal used. Then test coupons may be made from this type of metal for immersion in the tank. However, a more conservative inspection schedule should be developed based upon this circumstantial data than indicated in the prior example.

8.6.2.3 Secondary Containment. If the tank operates at close to atmospheric pressure and a leak would not cause undue detriment to personnel, property, or the environment if the leak were collected in a secondary containment system, then some reduction could be considered in the frequency of the internal tank inspection. Obviously, if the material stored were volatile and toxic upon inhalation or if the waste were highly reactive with water (rain) or with the material of construction used for the containment system, then this approach would not be suitable.

Other considerations include the size of the tank or quantity of material which might be leaked to the secondary containment system. Upon detection of a leak it may be possible to rapidly pump the tank's contents to an alternative tank as a temporary measure and thus avoid too large a spill. Of course, good housekeeping combined with frequent inspections would be required to assure that any leaks were detected soon after failure. The difficulty in cleaning up a spill should also be considered. Because of the difficulty in inspecting insulated tanks for leaks, reliance on secondary containment and early leak detection in this situation would not be practical.

Another problem emerges with tanks where the bottom rests directly on a foundation such that the bottom cannot be externally inspected. Obviously, the foundation must be within the secondary containment system. Furthermore, if pitting or other forms of non-uniform corrosion are experienced in the bottom, a leak may be present for a significant period of time before it becomes detected. During this period of time, considerable further deterioration of the tank may continue leading to a major failure.

Particular attention should be given to avoiding ignition of hazardous wastes if they are combustible . Use of expolosision-proof motors and prohibit of nearby motor vehichles and the like near the secondary containment system. Also, there should be no possibility of mixing incompatible wastes in the same secondary containment area if simultaneous leaks were to occur.

CHAPTER CONTENTS

9.0 SPILLS, LEAKS, AND SECONDARY CONTAINMENT
- Response to Spills and Leaks
- Secondary Containment
    - Runoff and Leachate Collection System
    - Peripheral Dike Systems
    - Liner Systems

References

9.0 SPILLS, LEAKS, AND SECONDARY CONTAINMENT

Chapter 9.0 is reserved for a possible future expanded discussion of the causes of spills and leaks and a minimal description of secondary containment. Some interim guidance on these matters is provided in the following pages which have been copied directly from a similar manual prepared by Fred C. Hart Associates, Inc. Other guidance should be obtained for the preparation of contingency plans including response to spills and leaks and in reviewing secondary containment systems.

Secondary containment systems are not generally required for tanks containing hazardous wastes. Nevertheless, as discussed in section 8.6.2.3 of this manual, under selected conditions the required frequency of tank inspection may be reduced if the tank has an effective secondary containment system.

Response to Spills and Leaks

Section 264.194(c) of the standards for inspection of hazardous waste tanks provides that owners or operators must specify the procedures they intend to use to respond to tank spills or leakage, including procedures and timing for expeditious removal of leaked or spilled waste and repair of the tank.

The procedures specified by the owner-operator will depend largely on site-specific circumstances. Factors will include the permeability of the area surrounding the tank, availablility of excess capacity for emptying the tank, and the materials of construction of the tank.

Table 9-1 summarizes the types of incidents likely to occur at a tank facility that should be addressed in the contingency plan.

Secondary Containment

Currently, EPA's hazardous waste regulations do not require a secondary containment system for tanks that treat or store hazardous waste. These systems are, however, effective means for detecting

TABLE 9-1. OPERATIONAL PROBLEMS OF TANKS*

Bulk Storage Facilities - Tank Farms and Tankage
• Overfilling of tanks
• Rupture of tanks
• Leaks in tanks, pipes, valves, and fittings
• Leaks in containment dikes
• Inadequate dike volume to hold contents of leaking tanks
• Water flow from diked area through open dike valve
• Leaks from pump seals and maintenance
• Level instrument failure allowing tank overfilling
• Piping damage by collision with mobile equipment
• Spills from tank bottom cleanout and sludge disposal
• Spills from pipe and tankage changes

* Oil spill prevention control and countermeasure plan review. A training program planned and presented by Rice University, University of Texas and Houston, and the U.S. EPA. The Pace Company, 1975.

and containing leaks and spills and are included in the design of many facilities. Some types of secondary containment are:

- runoff and leachate collection systems
- peripheral diking systems
- liner systems.

Runoff and Leachate Collection Systems

These systems should be constructed of materials compatible with the waste and should be designed to include:

- a slope of greater than one percent away from the tank or the collection point
- a collection point where runoff or precipitation can be routed so that it can be removed
- capacity equal to the volume of the largest tank or 10 percent of the volume of all the tanks in the containment system and allowance for precipitatior
- sufficient freeboard for sumps (if applicable).

Peripheral Dike Systems

Peripheral drainage collection can serve two purposes: it can prevent precipitation from entering the contained system, and it can contain leaks, runoff, and precipitation within the system. An acceptable design for a tank diking system should include the following:

- a capacity equal to the volume of the largest tank or 10 percent of the volume of all tanks (whichever is greater) in the containment system
- walls that are designed to be liquid tight and to withstand a full hydrostatic head. The slope of earthen walls should be consistent with the soil's angle of repose
- piping (which passes through dike walls) that is liquid tight and designed to prevent excessive stresses as a result of settlement

- relatively impermeable ground within the dike area to preclude ground-water or surface-water contamination
- a drain (such as drain pipes or grates) with control valves for the systematic collection and drainage of runoff, leakage, and precipitation from the diked area Alternatively, a sump system that can be drained utilizing a portable pump may be installed
- diked area should be kept free of drums, debris, etc.

For structural stability purposes, earthfill dikes should have side slopes of horizontal to vertical no greater than two to one. Additionally, a cutoff joining the base of the dike with the underlying soil is recommended to "key" the dike into the indigenous soil.

Liner Systems

A liner is a continuous layer of natural or man-made materials, beneath or on the sides of a containment system, that restricts the downward or lateral escape of hazardous waste, hazardous waste constituents, or leachate. The purpose of a liner for a tank storage facility is to prevent hazardous waste from coming in contact with the soil or surface or ground water. Liners may or may not be used at a facility. If liners are used, they may be found under or on top of the containment area or in other unique applications. A variety of natural and synthetic materials are available for use as liners. Their selection is generally based on the following factors:

- degree of impermeability (and thickness) required
- hydraulic head of waste
- availability of the material
- costs.

See EPA's technical resource document titled Lining of Waste Impoundment and Disposal Facilities[3] for further information on liners.

REFERENCES

1. "Flammable and Combustible Liquids", National Fire Protection Association, NFPA 30, 1981. Quincy, Massachusetts, 1980.
2. Oil spill prevention control and countermeasure plan review. A training program planned and presented by Rice University, the Universities of Texas and Houston, and the U.S. Environmental Protection Agency. The Pace Company, 1975.
3. Lining of Waste Impoundment and Disposal Facilities. Office of Water and Waste Management, U.S. EPA SW-870, September, 1980.

REACTIONS IN TANKS

10.1 Chemical Oxidation

- 10.1.1 Oxidation Processes
- 10.1.2 Types of Wastes Treated by Chemical Oxidation
- 10.1.3 Process Design and Operating Parameters
  - (a) Type of Tank
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10.3 Neutralization

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10.4 Precipitation, Flocculation, and Sedimentation

- 10.4.1 Precipitation
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  - (a) Iron and Steel Industry
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- 10.4.5 Environmental Considerations

10.0 REACTIONS IN TANKS*

The service life of a tank can be prematurely shortened because of interactions among the wastes with other wastes, with the tank's construction materials, and with the treatment process or treatment reagents. To avoid adverse effects, the regulation (40 CFR 264.13) requires that a waste analysis be performed before treating, storing, or disposing of hazardous waste. In addition to this general requirement, the operating requirements for tanks [40 CFR §264.192(a)] state that "wastes and other materials (e.g., treatment reagents) which are incompatible with the material of construction of the tank must not be placed in the tank unless the tank is protected from accelerated corrosion, erosion, or abrasion through the use of: (1) An inner liner or coating which is compatible with the waste or material...; or (2) Alternative means of protection."

The following are common operating problems associated with in-tank processes discussed in this chapter.

1. Corrosion. Corrosion of a tank may be accelerated by the treatment process itself or by the chemical reagents used to treat the waste. For example, chromic acid (an oxidizing agent) generally corrodes all metals. It would therefore be inappropriate to treat chromic acid by neutralization or precipitation in a steel tank unless the tank is lined with a material that is relatively inert to chromic acid (e.g., glass, polyethylene, or PVC).

2. Salting and scaling. Salting and scaling is the formation of an insulating layer at heat transfer surfaces that could contribute to the failure of tanks and the subsequent escape of hazardous waste to the environment. Salting and scaling may be reduced or prevented by preliminary treatment of the influent waste stream or by other operational controls.

3. Pressure and heat. High pressure or heat caused by mixing wastes that collectively generate large amounts of gaseous emissions or result in an exothermic reaction may cause tanks to explode, warp, or weaken unless the tank has been designed to withstand high pressure or temperature. Toxic or flammable gases may also be emitted as a result of process reactions.

4. Liquid flow rate and mechanical abrasion. Mechanical abrasion from materials contained in the waste, high liquid flow rates, or high velocity mixing, may damage the construction materials of tanks, pumps, or ancillary equipment. Points of contact experiencing the most wear are, for example, nozzle necks, pump cases, valve seats, and pipe fittings. In order to prevent erosion, it is important to match the construction material of the tank and ancillary equipment with the abrasion characteristics of the wastes expected to be treated, the anticipated liquid flow rate of the treatment process, and the energy generated or dissipated by mixing devices.

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* Source: "Draft Permit Guidance Manual - Tanks", July, 1981, by T. P. Senger and Fred C. Hart Associates, Inc., for the Environmental Protection Agency. Washington, D.C.

In order to determine whether a treatment process and its associated reagents are suitable for the treatment of a particular waste within a particular type of tanks, one must consider several factors. A treatment trial test can be conducted to examine the possibility of heat evolution or gas evolution, the compatibility of the treatment process intermediates and end products, and the compatibility of any added reagents with the tank's construction materials and design features.

This chapter is meant to provide an overview of the treatment processes that commonly occur in tanks and the possible interactions of the treatment processes with a tank. The five treatment processes described herein and the potential areas of process-tank interaction are as follows:

(1) chemical oxidation - corrosion, abrasion owing to mixing, high heat;

(2) chemical reduction - corrosion, abrasion owing to mixing, high heat;

(3) neutralization - corrosion, high heat or pressure, abrasion owing to mixing;

(4) precipitation - corrosion, abrasion due to mixing, scaling;

(5) sedimentation - corrosion, salting, scaling.

10.1 CHEMICAL OXIDATION

10.1.1 Oxidation Processes(2)

The processes discussed here are based on chemical oxidation as differentiated from thermal, electrolytic, and biological oxidation. Chemical oxidation is a process in which the oxidation state of a substance is increased (i.e., the substance loses electrons). Chemical oxidation in water and wastewater treatment is a method for detoxifying objectionable and/or toxic substances. These substances include:

- inorganic substances (e.g., Mn^{2+}, Fe^{2+}, S^{2-}, CN^-, SO_3^{2-});
- organic substances (e.g., phenols, amines, humic acids, odor- or color-producing or toxic compounds, bacteria, and algae).

Chemical oxidation processes most often used include:

- oxygenation or aeration;
- ozonation
- oxidation with hydrogen peroxide (very limited use);
- oxidation with potassium permanganate;
- chlorination or hypochlorination;
- oxidation with chlorine dioxide;
- oxidation with chromates or dichromates.

Table 10-1 is a listing of oxidants used to treat various wastes.

TABLE 10-1. OXIDATION WASTE TREATMENT APPLICATIONS(3)

Oxidant	Waste
Ozone	Phenols
Air (atmospheric oxygen)	Chlorinated hydrocarbons Sulfites Sulfides Ferrous iron
Chlorine gas	Sulfide Mercaptans
Chlorine gas and caustic	Cyanide
Chlorine dioxide	Cyanide Diquat Paraquat
Sodium hypochlorite	Cyanide Lead
Calcium hypochlorite	Cyanide
Potassium permanganate	Cyanide - organic odors Lead Phenol Diquat Organic sulfur compounds Rotenone Formaldehyde
Permanganate	Manganese
Hydrogen peroxide	Phenol Cyanide Sulfur compounds Lead
Nitric acid	Benzidene

10.1.2 Types of Waste Treated by Chemical Oxidation(3)

Liquids are the primary waste form treatable by chemical oxidation. The most powerful oxidants are relatively nonselective; any easily oxidizable material in the waste stream will, therefore, be treated. For example, if an easily oxidizable organic solvent was used, little of the chemical effect of the oxidizing agent would be available for further oxidation.

Gases have been treated by scrubbing with oxidizing solutions for the destruction of odorous substances, such as certain amines and sulfur compounds. Potassium permanganate, for instance, has been used in certain chemical processes, in the manufacture of kraft paper, and in the rendering industry. Oxidizing solutions are also used for small-scale disposal of certain reactive gases in laboratories.

Oxidation has limited application to slurries, tars, and sludges. Because other components of the sludge, as well as the material to be oxidized, may be attacked indiscriminately by oxidizing agents, careful control of pH, etc., are required to ensure that the desired components are being oxidized.

Chemical oxidation can be used to treat both organic and inorganic waste components. Since some oxidizing agents may react violently in the presence of significant quantities of readily oxidizable organic material, either the organic matter or the oxidizing agent should be added slowly. Sudden large additions should be avoided.

The primary use of chemical oxidation for hazardous waste treatment is in the conversion and destruction of cyanides from plating operations where metals, such as zinc, copper, and chromium, are present.

10.1.3 Process Design and Operating Parameters

As a physicochemical process, the design of a system for the chemical oxidation of a waste material involves considering the following design and operating parameters:

- type of tank (or reactor);
- mixing;
- location of inlet and outlet pipes;
- pH or other process control;
- temperature control;
- materials selection.

Both tank selection and materials selection are discussed below.

(a) Type of Tank. Types of vessels, containers, or tanks (commonly called reactors) in which chemical and biological reactions are carried out include batch, plug flow, continuous, packed, or fluidized bed.

(b) Selecting Materials for the Oxidation Process. When selecting the materials of construction for the oxidation process, one must protect the tank against the corrosive effects of the oxidizing agent. Specifying a material of construction usually involves three stages: listing the requirements, selecting and evaluating the candidate materials, and choosing the most cost-effective material. A valuable source of information on selection of materials of construction is "How to Select Materials" in the November 3, 1980, issue of Chemical Engineering (reprints of which are available).

The most important factor in selecting material is performance regarding corrosion. The information listed in Table 10-2 is valuable in estimating materials' corrosion performance. Additional information on corrosion is provided in the technical resource document titled "Compatibility of Wastes in Hazardous Waste Management Facilities."(7)

10.2 CHEMICAL REDUCTION

10.2.1 Reduction Processes(8)

Reduction-oxidation, or Redox, reactions are those in which the oxidation state of at least one reactant is raised while that of another is lowered. Reduction is used to treat wastes in such a way that the reducing agent lowers the oxidation state of a substance, reduces its solubility, or transforms it into a form that can be more easily handled.

Base metals such as iron, aluminum, zinc and sodium compounds are good reducing agents. Sulfur compounds are among the more common reducing agents.

10.2.2 Types of Waste Treated by Chemical Reduction(8)

Liquids are the primary waste form treatable by chemical reduction. The most powerful reducing agents are relatively nonselective; any material in the waste stream that is relatively easily reduced can, therefore, be affected.

Reduction has limited application to slurries, tars, and sludges, because of the difficulties of achieving intimate contact between the reducing agent and the hazardous constituent. Consequently, the reduction process would be very inefficient. In general, hazardous materials occurring as powders or other solids would usually have to be dissolved prior to chemical reduction.

Table 10-3 lists some of the more common wastes and reducing agents that undergo the reduction process.

TABLE 10-2. INFORMATION FOR ESTIMATING CORROSION AGAINST PERFORMANCE(5)

Process Conditions

- Main constituents (identity and amount) of waste
- Impurities (identity and amount) in waste
- Temperature
- pH
- Degree of aeration
- Velocity of agitation
- Pressure
- Estimated range of each variable
- Environmental conditions

Type of Application

- What is function of part or equipment?
- What effect will uniform corrosion have on serviceability?
- What effect will localized corrosion have on usefulness?
- Will there be stresses present? Is stress-corrosion cracking a possibility? Are crevice or pitting corrosion likely to occur?
- Is design compatible with the corrosion characteristics of the material?
- What is the desired service life?

Experience

- Has material been used in identical situations? With what specific result?
- If equipment is still in operation, has it been inspected?
- Has material been used in similar situation? What was performance, and specifically, what are differences in old and new situation?
- Any pilot-plant experience?
- Any plant corrosion-test data?
- Have laboratory corrosion tests been run?
- What literature is available?

TABLE 10-3. REDUCTION WASTE TREATMENT APPLICATIONS(8)

Waste	Reducing Agent
Chromium (VI)	Sulfur dioxide (often flue gas)
	Sulfite salts sodium bisulfite sodium hydrosulfite
	Ferrous sulfate
	Waste pickle liquor
	Powdered waste aluminum
Mercury	Powdered metallic zinc
	Sodium borohydride
Tetra-alkyl-lead	Sodium borohydride
Silver	Sodium borohydride

10.2.3 Process Design and Operating Parameters

Analogous to the oxidation process, the design of a system for the chemical reduction of a waste material involves the following design and operating parameters:

- type of tank (or reactor);
- reaction rates;
- mixing;
- location of inlet and outlet pipes;
- pH control;
- temperature control;
- materials selection.

Both type of tank and materials selection have been discussed in the oxidation section of this chapter.

In general, very simple equipment is required for chemical reduction. This includes storage vessels for the reducing agents and perhaps for the wastes, metering equipment for both streams, and contact vessels with agitators to provide suitable contact of reducing agent and waste. Some instrumentation is required to determine the concentration and pH of the waste and the degree of completion of the reduction reaction. The reduction process may be monitored by an oxidation-reduction potential (ORP) electrode. This electrode is generally a piece of noble metal (often platinum) that is exposed to the reaction medium and produces an EMF (electromotive force) output that is empirically relatable to the reaction condition by revealing the ratio of the oxidized and reduced constituents.

10.3 NEUTRALIZATION(9)

10.3.1 Process Description

The process of neutralization is the interaction of an acid with a base. The term "neutralization" is often used to describe adjustment of pH to values within the neutral range of 6.0 to 9.0.

The actual process of neutralization is accomplished by the addition of an alkaline material to an acidic material or by adding an acidic to an alkaline material, as determined by the required final pH. The primary products of a neutralization reaction are a salt and water.

10.3.2 Application of Neutralization Process

Neutralization is a treatment process of demonstrated technical and economic feasibility that is in full-scale use in a wide spectrum or industries. A sample list of industries employing this process is presented in Table 10-4. Neutralization finds its widest application in the treatment of aqueous wastes containing strong acids such as sulfuric and hydrochloric, or strong bases such as caustic soda and sodium hydroxide. The process can, however, be used with nonaqueous materials (for example, acidic phenols, which are insoluble in water). Although neutralization is a liquid phase phenomenon, it can also treat both gaseous and solid waste streams. Gases can be handled by absorption in a suitable liquid phase, as in the case of alkali scrubbing of acid vapors. Slurries can be neutralized, with due consideration for the nature of the suspended solid and its dissolution properties. Sludges are also amenable to pH adjustment, but the viscosity of the material complicates both the process of physical mixing and the resultant contact between acid and alkali, which is essential to the treatment. In principle, even tars can be neutralised, although the problems of reagent mixing and contact are usually severe, making the process impractical in most instances. Solids and powders that are acidic or basic salts can also be neutralized if they are dissolved prior to initiating the neutralization process.

Some of the more common applications for pH treatment of acidic and alkaline wastes are described in the following paragraphs.

Acid Exhausts - Industrial processes that utilize acids, e.g., sulfuric, nitric, or hydrochloric, frequently have problems with acid mist in the exhaust. Scrubbing with water on packed bed columns produces an acid-free gas, but the spent water must be neutralized. Alkali is usually added automatically to produce a water stream with a pH of 6.5-7.5 that can be discharged or recycled. In similar systems, flue gas desulfurization units absorb and neutralize sulfur oxides with alkalies such as lime, limestone, dolomite, or caustic soda.

Petrochemical Waste Streams - Neutralization is applied to: (1) washwaters, acid or alkaline, (2) spent caustics, (3) acid sludges, or (4) spent acid catalysts. Sulfuric acid and carbon dioxide from flue gases are both used to treat spent caustic wastes. Pits filled with lime, limestone, and even oyster shells (a source of calcium carbonate) are utilized to neutralize spent acid sludges.

Sulfuric Acid Pickle Liquor - In small-scale operations (less than 5,000 gpd) neutralization of pickle liquor from steel cleaning operations can be performed in a batch process, usually with quicklime. Typically, pickle liquor contains on the order of 70 grams of iron and 170 grams of sulfate per liter (approximately 5 percent sulfuric acid by weight). Large waste streams can be handled in continuous flow systems, and other suitable alkaline agents may be employed. If calcium-based materials are utilized in the neutralization,

TABLE 10-4. MAJOR INDUSTRIES USING NEUTRALIZATION(9)

Industry	Wastewater pH Range
Pulp and paper	Acidic and basic
Dairy products	Acidic and basic
Textiles	Basic
Pharmaceuticals	Acidic and basic
Leather tanning and finishing	Acidic and basic
Petroleum refining	Acidic and basic
Grain milling	Acidic and basic
Fruits and vegetables	Acidic and basic
Beverages	Acidic and basic
Plastic and synthetic materials	Acidic and basic
Steel pickling	Acidic
By-product coke	Basic
Metal finishing	Acidic
Organic chemicals	Acidic and basic
Inorganic chemicals	Acidic and basic
Fertilizer	Acidic and basic
Industrial gas products	Acidic and basic
Cement, lime, and concrete products	Basic
Electric and steam generation	Acidic and basic
Nonferrous metals-aluminum	Acidic

calcium sulfate will form a product sludge, which is usually dewatered by vacuum filtration or placed in a lagoon. The formation of a flocculated ferrous hydroxide precipitate (at neutral pH) can produce a solid with poor settling and filtering properties. Thus an oxidation step is often employed since ferric hydroxide is very insoluble, and there is an optimum ratio of ferric to ferrous ions at which the sludge can be handled most readily.

10.3.3 Types of Tanks

The required equipment for neutralization is simple: storage and reaction tanks with accessory agitators and delivery systems. The tanks may be of any shape, but must be properly baffled to allow adequate mixing and prevent "short-circuiting". Frequently, the neutralization is carried out in a series of tanks to provide better control of the final pH.

Appropriate instrumentation must be provided and include pH measurement (and possible recording) devices with appropriate sample pumps. The feed of neutralizing agent may be regulated automatically by the pH monitoring unit, depending on the requirements of the individual system.

The design of storage facilities for neutralizing agents depends on the chemical reagents employed in the treatment process. Caustic solutions and acids may be stored in the open, but quicklime should be kept in waterproof silos, hoppers, or even bags. Delivery systems depend on the physical form of the reagents. Liquids may be transferred with pumps, while slurries can be moved through gravity piping, pumps, or open flumes. Ancillary equipment might include installations such as equalization basins, clarfiers, or vapor removal systems, depending on the specific neutralization scheme.

In dealing with acids and alkalines, appropriate materials of construction are required to provide reasonable service life for equipment. Corrosion may result in deterioration of a construction material, e.g., lead is attacked by hydrochloric acid. In many cases, the specific concentration of a reagent is important in selecting the correct material used in pumps, pipes, tanks, etc. Examples of materials recommended for handling different acids and alkalies at ambient temperature are:

sulfuric acid (75-95 percent concentration) - lead
(10 percent concentration) - lead or rubber

hydrochloric acid (concentrated or dilute) - rubber

sodium hydroxide (concentrated) - 316 stainless steel (SS) or rubber
(dilute) - 316 stainless steel (SS), rubber, carbon steel, or cast iron

calcium hydroxide - 316 SS, rubber, or carbon steel.

Other less commonly used materials include glass, metal alloys such as monel, plastics, such as PVC, and even wood. The expense of such materials frequently precludes their use except for small-scale applications or in situations where there is no alternative. It is important to realize that a vessel need not be constructed entirely of one material; it may be lined with lead, rubber, glass, plastic, or other corrosion-resistant materials. Expected length of service, temperature of operation, desired physical strength, liquid flow rate, and mechanical abrasion are some of the other factors to be considered in selecting materials.

In general, fiberglass tanks or tanks lined with an organic material are used for storing acids that present corrosion problems in contact with most metals.

10.3.4 Environmental Impacts

After neutralization a waste stream will usually show an increased total dissolved solids content because of the addition of the chemical agent, but there may also be an accompanying reduction in the concentration of heavy metals if the treatment proceeds to the basic pH range. Conversely, in neutralization involving the addition of acid to alkali, there is the possibility of dissolution of metal-containing solids. This may, on occasion, be disadvantageous, particularly if the suspended matter is slated for removal, e.g., by filtration. For example, the anions resulting from neutralization of sulfuric and hydrochloric acids are sulfate and chloride, respectively. These ions are not considered hazardous, but there are recommended limits for discharge, based primarily on problems in drinking water. The common cations present after neutralization involving caustic soda and lime (or limestone) are sodium and calcium (possibly magnesium), respectively. These ions are not toxic and there are no recommended limits; calcium and magnesium are, however, responsible for water hardness and the accompanying scaling problem. Limestone neutralization converts the carbonate to harmless carbon dioxide gas.

With regard to atmospheric emissions, one must be cautious not to neutralize wastewater streams indiscriminately. Acidification of streams containing certain salts, such as sulfide, will produce toxic gases. If there is no satisfactory alternative, the gas must be removed through scrubbing or some other treatment. In cases where solid products are formed (as in the precipitation of calcium sulfate, or heavy metal hydroxides), clarifier/thickeners and filters must be provided. If the precipitate is of sufficient purity, it would be a salable product; otherwise, a disposal scheme must be devised.

10.4 PRECIPITATION, FLOCCULATION, AND SEDIMENTATION(11)

Precipitation, flocculation, and sedimentation are discussed together in a single section because in waste treatment they are most commonly used together, as consecutive treatments to the same stream. Precipitation removes a substance in solution and transforms it into a second phase, often in the form of solid particles that may be small or even colloidal. Flocculation transforms small suspended particles into larger suspended particles so that they can be more easily removed. Sedimentation removes the suspended particles from the liquid.

10.4.1 Precipitation

(a) Process Description. Precipitation is a physicochemical process whereby some or all of a substance in solution is transformed into the solid phase and thereby removed from solution. Precipitation involves an alteration of the chemical equilibrium relationships affecting the solubility of the component(s). This alteration can be achieved by a variety of means. Most precipitation reactions for industrial or waste treatment purposes are induced by one or a combination of the following steps:

- adding a substance that will react directly with the substance in solution to form a sparingly soluble compounds,
- adding a substance that will cause a shift in the solubility equilibrium to a point that no longer favors the continued solubility of the substance originally in solution
- changing the temperature of a saturated or nearly saturated solution in the direction of decreased solubility; since solubility is a function of temperature, this change can cause ionic species to come out of solution and form a solid phase.

The most common precipitation reactions involve the removal of inorganic ionic species from an aqueous medium. For example, zinc chloride is highly soluble in water, as is sodium sulfide. Zinc sulfide, however, has an extremely low solubility in water. Thus, if an aqueous solution of zinc chloride is mixed with an aqueous solution of sodium sulfide, zinc ions and sulfide ions will rapidly combine to form solid zinc sulfide particles.

It is important to recognize that the term "precipitation", as strictly defined, refers only to the conversion of dissolved substances into insoluble ones in order to facilitate their subsequent removal from the liquid phase. Precipitation per se does not refer to any of the liquid-solid separation processes that are required to remove the precipitated solid particles from the original volume of liquid. In order to effect the removal of precipitated particles from a volume of liquid, it is very often necessary to apply additional process steps, and these often involve flocculation, sedimentation, and/or some control that will determine the final particle size--and produce an easily separable solid (or crystal).

(b) Process Design and Operating Parameters. The parameters of interest for precipitation include the time required for reaction, the solubility product of the substance to be precipitated, and the effect of the reaction upon the tank construction materials and types of tanks.

Physically, most precipitation reactions are carried out by adding the appropriate chemicals to the solution and mixing thoroughly. Reagents should be added in a manner that minimizes contact of the concentrated reagent with the tank surface. Although most precipitation reactions take place extremely rapidly, a moderate amount of time is usually required to allow the chemicals to be dispersed throughout the solution. Characteristically, the solid particles, when first formed, are very small. Depending on the nature of the chemical system involved and the types of further treatment applied, the solid particles can remain as submicroscopic precipitation nuclei, or very small colloidal particles; or they can grow into larger particles. Since mixing can shorten the dispersion time of chemicals, some type of mixing equipment should be used.

The solids formed by precipitation are salts and should not pose severe corrosion problems. The chemicals added to the waste in order to induce precipitation are, however, often corrosive in nature, such as concentrated hydroxides or strong acids. Again, caution should be taken when adding these chemicals to the waste and upon mixing of the chemicals in order to minimize contact of concentrated agents with the tank surface.

10.4.2 Flocculation

(a) Process Description. The term "flocculation" as defined here encompasses all of the mechanisms by which the suspended particles agglomerate into larger particles, including the addition of flocculating agents.

Many liquid-solid separation processes, such as sedimentation, are based on the use of gravitational and/or inertial forces to remove solid particles from a liquid. It is generally true that the larger the particle size, the easier will be the removal of the particle from the liquid.

A variety of mechanisms is involved in flocculation whereby small particles are made to form larger particles.

Most of these mechanisms involve surface chemistry and particle charge phenomena. In simple terms, these various phenomena can be grouped into the following two sequential mechanisms:

- chemically-induced destabilization of the repulsive surface-related forces, thus allowing particles to stick together when contact between particles is made;
- chemical bridging and physical enmeshment between the now nonrepelling particles, thus allowing for the formation of large particles.

Once suspended particles have been flocculated into larger particles, they can usually be removed from the liquid by sedimentation, provided a sufficient density difference exists between the suspended matter and the liquid.

As in precipitation, the solids formed by flocculation are salts and should not pose severe corrosion problems. Chemical reagents that are corrosive in nature should, however, be added to a tank and mixed with caution, so as to minimize contact of the reagent with the tank surface.

10.4.3 Sedimentation

(a) Process Description. Sedimentation is a physical process whereby particles suspended in a liquid are made to settle by means of gravitational and inertial forces acting on both the particles suspended in the liquid and the liquid itself. Basically, particles settle out of a liquid by creating conditions in which the gravitational and inertial forces acting on the particle in the desired direction of settling are greater in magnitude than the various forces (drag forces, inertial forces) acting in the opposite direction. This force differential causes the particles to travel in the desired direction.

The fundamental elements of most sedimentation processes are:

- a tank or container of sufficient size to maintain the liquid in a relatively quiescent state for a specified period of time;
- a means of directing the liquid to be treated into the tank in a manner that is conducive to settling;
- a means of physically removing the settled particles from the liquid (or the liquid from the settled particles, whichever the case may be).

Sedimentation can be carried out as either a batch or a continuous process. Continuous processes are by far the most common, particularly when large volumes of liquid are to be treated.

Depending on the specific process configuration, the settled particles are either removed from the bulk of the liquid, or the liquid is separated from the settled particles by decantation. The end result, and single purpose, of sedimentation is the separation of liquids from solids. The fraction of liquid containing the settled particles is commonly referred to as "sludge".

(b) Process Design and Operating Parameters. Because sedimentation is purely a physical separation, the type of tank used to provide the separation is the most important factor. Since there is little control over the particle size or density, the only method that can be used to accommodate these factors is to design tanks to handle the different settling characteristics of various wastes.

Sedimentation can be carried out in rudimentary settling ponds (surface impoundments), conventional settling basins, or in more advanced clarifiers that are often equipped with built-in flocculation zones and tube-like devices that enhance settling.

In settling ponds, the liquid is merely decanted as the particles accumulate on the bottom of the pond and eventually fill it. Often the pond is periodically scraped by mechanical shovels, draglines, or siphons. Sedimentation basins and clarifiers are more sophisticated and usually employ a built-in solids collection and removal device such as a sludge scraper and draw-off mechanism. Sedimentation basins tend to be rectangular in configuration, usually employ a belt-like collection mechanism, and tend to be used more for the removal of easily settleable particles from a liquid.

Clarifiers are generally circular and are usually used in applications that involve precipitation and flocculation in addition to sedimentation. Very often all three processes take place within the same piece of equipment, since many clarifiers are equipped with separate zones for chemical mixing and precipitation, flocculation, and settling. Certain clarifiers are equipped with low lift turbines that mix a portion of the previously settled precipitates with the incoming feed. The practice has been shown to enhance certain precipitation reactions and promote favorable particle growth.

There are many variations of the sedimentation process, encompassing a wide variety of commercially available equipment.

10.4.4 Precipitation, Flocculation, and Sedimentation Applications to Hazardous Wastes

The processes of precipitation, flocculation, and sedimentation are finding widespread application in the treatment of wastewater streams containing soluble heavy metals and colloidal hazardous substances. A summary of general wastewater treatment applications in a number of major industries is presented below.

(a) Iron and Steel Industry. Wastewater streams from the iron and steel industry are characterized by a very high concentration of settleable suspended particles and a relatively low concentration of dissolved heavy metals, such as ferric iron, zinc, lead, chromium, and manganese. Sedimentation is currently in widespread use for the removal of suspended solids. Precipitation (usually with lime and alum) is used to remove heavy metals.

(b) Aluminum Industry. Wastewater streams from the aluminum industry contain high concentrations of soluble fluoride salts. The commonly used treatment process entails precipitation as calcium fluoride (with lime), flocculation, and sedimentation to remove the fluoride as solid particles.

(c) Copper Industry. Wastewater streams from copper smelting and refining contain a variety of soluble and colloidal heavy metals (arsenic, cadium, copper, iron, lead, mercury) that can be removed, to varying degrees of effectiveness, by precipitation, flocculation, and sedimentation using either lime or sodium sulfide.

(d) Metal Finishing Industry. Soluble salts of copper, nickel, cadmium, and chromium are removed from wastewater streams by precipitation, for example, by utilizing lime to form insoluble hydrated oxides followed by flocculation, and sedimentation. Chromium usually present as chromate or dichromate must first be reduced to the trivalent state so that the precipitation process will be effective.

(e) Inorganic Chemicals Industry. Many manufacturing processes within the inorganic chemicals industry produce wastewaters that contain suspended solids and soluble heavy metals. Manufacture of titanium dioxide and chromium pigments produce such wastewaters. Precipitation, flocculation, and sedimentation are used to treat many of these wastewaters.

(f) Sludge Thickening. The first step used in a sludge dewatering process is often simply a better sedimentation process commonly referred to as "sludge thickening" or "gravity thickening". In the gravity thickening, the sludge is sent to a type of clarifier in which the already settled solid particles are allowed to settle further and compact. Typically, the supernatent liquid is returned to the main clarifier that performs the initial liquid-solid separation, while the "thickened" sludge is drawn off and either disposed of or sent to further dewatering steps, such as vacuum filtration or centrifugation.

10.4.5 Environmental Considerations

Since precipitation, flocculation, and sedimentation processes are basically liquid-solid separation processes, two output streams will result - a high-volume purified liquid stream and a low-volume slurried solids stream. There are usually no air emissions from the process. The processes do employ equipment that exposes large open surfaces of liquid to the atmosphere, and, if that liquid is other than water and is highly volatile or contains highly volatile components, air emissions could result.

REFERENCES

(1) 40 CFR 264.192(a), Subpart J (46 Fed. Reg. 2867 [January 12, 1981]).

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(5) Michael Henthorne, "Understanding Corrosion", Chemical Engineering Deskbook, Vol. 79, No. 27, December 4, 1972, p. 19.

(6) Gary W. Kirby, "How to Select Materials", Chemical Engineering, November 3, 1980, pp. 87-130, Reprint No. 046.

(7) "Compatibility of Wastes in Hazardous Waste Management Facilities: A Technical Resource Document for Permit Writers", Fred C. Hart Associates, Inc., for U.S. EPA, Office of Solid Wastes, Washington, D.C., 1982.

(8) Nancy J. Cunningham, Physical, Chemical and Biological Treatment Techniques for Industrial Waste, Arthur D. Little, Inc., Cambridge, Mass., November, 1976, Chapter 38.

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(10) 40 CFR 264 and 265 (45 Fed. Reg. 76076-83 [November 17, 1980]).

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APPENDIX A CONTENTS

Table A-1. Regulatory Analysis of Tanks

APPENDIX A

TABLE A-1 REGULATORY ANALYSIS OF TANKS

Section of 40 CFR	The Preferred Section Number of Permit Application Outline[(a)]	Subject Covered
270.16	D-2a	Tanks to store or treat hazardous wastes
(a)	D-2a	Reference to design standards or other information for design and construction of the tank
(b)	D-2b	Description of design specifications and corrosion and erosion characteristics of construction/lining materials
(c)	D-2a	Tank dimensions, capacity, and shell thickness
(d)	D-2c	Process flow diagram (PFD) and piping and instrumentation diagram (P&ID)
(e)	D-2a	Description of feed systems, safety cutoff, bypass systems, and pressure controls (e.g., vents)
(f)	D-2c	Description of procedures for handling incompatible, ignitable or reactive wastes, including the use of buffer zones
264.190		Applicability
264.190(a)		Applicable to owners/operators of facilities that use tanks to treat or store hazardous waste
264.190(b)		Does not apply to facilities that use covered underground tanks that cannot be entered for inspection
264.191	D-2a	Design of tanks

TABLE A-1 (Continued)

Section of 40 CFR	The Preferred Section Number of Permit Application Outline(a)	Subject Covered
264.191(a)	D-2a	Tanks must have sufficient shell strength and pressure controls (e.g., vents to assure that they do not collapse or rupture. The Regional Administrator will review the design of tanks, including the foundation, structural support, seams and pressure controls. Minimum shell thickness must be maintained at all times to ensure sufficient shell strength; factors to be considered include the width, height, and materials of construction of the tank, and the specific gravity (S.G.) of the waste. Regional Administrator shall rely upon appropriate industrial design standards and other available information.
264.192	D-2c	General operating requirements
264.192(a)	D-2b	Materials which are incompatible with the materials of construction of the tank must not be placed in the tank unless protected from accelerated corrosion, erosion, or abrasion :
264.192(a)(1)	D-2b	Through inner liner or coating
264.192(a)(2)	D-2b	Through cathodic protection or corrosion inhibitors.
264.192(b)	D-2c	Must use practices to prevent overfilling of the tank
264.192(b)(1)	D-2c	Controls such as waste feed cutoff system or bypass system to a standby tank

TABLE A-1 (Continued)

Section of 40 CFR	The Preferred Section Number of Permit Application Outline[(a)]	Subject Covered
264.192(b)(2)	D-2c	For uncovered tanks, maintenance of sufficient freeboard to prevent overtopping by wave or wind action or precipitation
264.194	F-2b(2)	Inspections:
264.194(1)	F-2b(2)	Overfilling control equipment--once each operating day
264.194(2)	F-2b(2)	Data gathered from monitoring equipment--once each operating day
264.194(3)	F-2b(2)	For uncovered tanks, the level of waste in the tank--once each operating day
264.194(4)	F-2b(2)	Construction materials of aboveground portions of tank to detect corrosion and leaking of fixtures and seams--weekly
264.194(5)	F-2b(2)	Area immediately surrounding the tank to detect obvious signs of leakage--weekly
264.194(b)	F-2b(2)	Owner or operator must develop a schedule and procedure for assessing the condition of the tank and safe procedures for emptying the tank. Frequency of these assessments must be based on: materials of construction of the tank, type of corrosion or erosion protection used, rate of corrosion observed during previous inspections, and characteristics of the waste.
264.194(c)	F-2b(2)	Procedures to respond to tank spills or leakage.
264.197	I-1d(2)	At closure, all hazardous waste and waste residues must be removed.

TABLE A-1 (Continued)

Section of 40 CFR	The Preferred Section Number of Permit Application Outline[a]	Subject Covered
264.198	F-5e	Special requirements for ignitable or reactive wastes
264.198(a)	F-5e	Ignitable or reactive waste must not be placed in a tank unless:
264.198(a)(1)	F-5e	The waste is treated so that the resulting waste no longer meets the definition of ignitable or reactive waste.
264.198(a)(2)	F-5e	or stored such that it is protected from any conditions which may cause ignition or reaction
264.198(a)(3)	F-5e	or the tank is used solely for emergencies
264.198(b)	F-5e	Compliance with the buffer zone requirements or NFPA's "Flammable and Combustible Liquids Code", 1977 or 1981.
264.199	F-5f	Special requirements for incompatible wastes as follows:
264.199(a)	F-5f	Must not be placed in the same tank unless 264.17(b) is complied with.[b]
264.199(b)	F-5f	Must not be placed in an unwashed tank which previously held an incompatible waste unless 264.17(b) is complied with.[b]

(a) Refers to the section number of the preferred outline for a Part B permit application as specified by A Guide For Preparing RCRA Permit Applications For Existing Storage Facilities, EPA (1982).

(b) Section 264.17(b) deals with operation so as to prevent explosion, fire, excessive heat, generation of fume, etc.

APPENDIX B CONTENTS

B.0 CORROSION AND DETERIORATION OF MATERIALS OF CONSTRUCTION
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APPENDIX B

CORROSION AND DETERIORATION OF MATERIALS OF CONSTRUCTION

Title 40 CFR 270.16(b) requires "a description of design specifications including identification of construction materials and lining materials (include pertinent characteristics such as corrosion and erosion resistance)". Part 264.192(a) requires that "wastes and other materials which are incompatible with the material of construction of the tank must not be placed in the tank unless the tank is protected from accelerated erosion or corrosion through the use of (1) an inner liner or coating which is compatible with the waste or material . . . or (2) alternative means of protection . . ." Sections 3.2.6 and 8.6 of this manual indicate the need for corrosion rate data and other information to calculate expected service life and the required inspection frequency of tanks.

The purpose of this Appendix is to present general information to the permit writer on how to approach the subjects of corrosion resistance, compatibility, and corrosion rate to assist him in judging compatibility and in writing the inspection frequency specification. Many companies have corrosion metallurgists and other specialists who make lifetime commitments to this field, and there is a large body of accompanying published and unpublished literature. Therefore, it is far beyond the scope of this manual to present specific data to cover specific situations. The information presented is necessarily general in nature and will often not be useful in the analysis of specific tanks and the liquid to be contained.

B.1 Materials of Construction

There is a large variety of materials of construction from which tanks, tank liners and coatings, and tank auxiliaries may be constructed. The National Association of Corrosion Engineers (NACE) Corrosion Data Survey attempts to report in its Metals Section corrosion data in tabular array for

26 different types of metals including mild steel, stainless steel, copper base alloys, nickel base alloys, aluminum, lead, and other expensive metals such as gold, tantalum, and zirconium. NACE, in its Non-Metals Section of the Corrosion Data Survey, reports similar data (where available) for up to 36 types of materials including many plastics (including fiber-reinforced plastics), carbon-graphite, ceramics, concrete, glass, glassed steel, rubbers, and wood.

It is well recognized that the proper selection of a material of construction involves an economic analysis to achieve lowest capital and maintenance costs over the anticipated lifetime of the project. In some cases where color or product purity is of concern such as in the chemical industry, this will be factored into the analysis; corrosion products may color products or be unacceptable impurities. Prudent management will usually specify materials that will be relatively trouble-free over the life of the project because forced shutdowns may result in production of off-grade product or lost sales revenues and profits. Therefore, selections of materials of construction are usually made using a conservative bias.

Historically, carbon steel tanks have been the least expensive. More recently, fiberglass-reinforced plastic (FRP) tanks have become generally less expensive than 304 stainless steel tanks of equal size. Because plant managers are more familiar with 304 stainless steel tanks and long-term service histories for FRP tanks are not available, 304 stainless steel tanks are usually specified unless such steel is attacked by the liquid to be stored. Stainless steel tanks may also be fabricated in larger sizes and, thus, where large volumes of liquids must be stored, economies of scale have been realized by specifying one large stainless steel tank instead of several small FRP tanks.

If carbon steel or FRP tanks would not provide satisfactory service, the next class of material of construction considered are the 304 or similar stainless steels (302, 321, or 347). Although seldom used, aluminum or aluminum alloys may be appropriate. Similarly, if the 304 series of stainless steels or aluminum is unsuitable, then the suitability of 316 stainless steel is reviewed; however, 316 stainless steel is relatively expensive and such a specifiction is made reluctantly if it would appear that 304 stainless steel is barely acceptable.

After the above steels have been considered, the next step is to review the possibility of using tanks lined with rubber, lead, or possibly coated with other non-metallics. Alternatively, special metal alloys may be considered at this cost level. The very costly noble metals such as titanium, tantalum, zirconium, and gold are specified only as a last resort.

Thus, when a material of construction is being selected for use with a chemical, the corrosion engineer will evaluate the compatibility of the low-cost materials first; if carbon (or mild) steel has a low corrosion rate of less than 2/1000 inch per year, then the properties of the stainless steels are of no interest. Conversely, if mild steel has a moderately low corrosion rate of less than 20/1000 inch per year, the engineer is likely to investigate the compatibility of the liquid with the 304 types of stainless steel and FRP, but not 316 types of stainless. This orientation has been used to prepare Table B-1, which shows the compatibility of common materials of construction with various chemicals. The specific chemicals included in the table were selected to represent each of the common classes of chemicals. Generally, assessment of compatibility was very severe; that is, unless the corrosion rate for metals was less than 2/1000 inch per year, the metal or FRP was shown in the table as incompatible. Although there are hazards in generalizing by the non-specialist, when the corrosive properties of a chemical on a material are unknown, the corrosion engineer is likely to base his suggestion for a material of construction by analyzing the corrosive properties of other chemicals that are chemically similar for which the corrosion characteristics are known.

As background the following sections present generalizations about the common construction materials used for tanks. This information should not be accepted as being adequate for specific situations.

B.1.1 Carbon Steels. Carbon or mild steel is the most commonly used steel in the petroleum and chemical industries.

- Can be used to store alkalies; for example, caustic soda can be stored in concentrations up to 75 percent at temperatures ranging to 212 F
- Only slightly subject to corrosion by brines and seawater

TABLE B-1. COMPATIBILITY OF MATERIALS OF CONSTRUCTION WITH VARIOUS CHEMICALS

	Compatible With	Incompatible With
Mineral Acids		
Sulfuric acid(1)	FRP(2) Mild steel Rubber-lined	
Hydrochloric acid(3)	FRP	Mild steel
Nitric acid	FRP(4)	Mild steel
Phosphoric acid	FRP	Mild steel
Organic Acids		
Acetic acid	FRP	Mild steel
Bases		
Sodium hydroxide	FRP Mild steel(5)	Mild steel(5)
Ammonium hydroxide	Mild steel(5) FRP(6)	Mild steel(5)
Aqueous Salts		
Calcium chloride	FRP	Mild steel(7)
Sodium sulfate	FRP	Mild steel
Copper sulfate	FRP	Mild steel
Ferric chloride	FRP	Mild steel
Sodium hypochloride	Special metal alloys	Mild steel
Stannous chloride	Stainless steel (ss) to 50% Noble metals	FRP
Sodium chloride	FRP	Mild steel
Alum	FRP	Mild steel

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(1) Numbers refer to notes at the end of the table.

TABLE B-1 (Continued)

	Compatible With	Incompatible With
Solvents		
Perchloroethylene	FRP(8)	Mild steel
Carbon tetrachloride	FRP(9)	Mild steel
Ethyl alcohol	Mild steel (10)	Stainless steel
Methyl ethyl ketone	FRP(11)	Mild steel (12)
Acetone	FRP (13)	Mild steel (14)
Miscellaneous		
Benzene	FRP (15)	Mild steel
Hexane	Mild steel (16)	FRP
Gasoline(17)	Mild steel FRP	
Aniline	Stainless steel(18)	FRP, mild steel
Nitrobenzene	FRP(19), mild steel	FRP
Phenol	Mild steel and stainless steel	
Chlorobenzene	Mild steel Stainless steel	
Naphthalene	Mild steel(20)	FRP(21)
Benzoic acid	special metals (nickel-base alloys)	Mild steel
Diethyl amine	Mild steel(22)	
Formaldehyde	FRP Stainless steel	Mild steel

TABLE B-1 (Continued)

(1) Needs the attention of a corrosion specialist. FRP is good up to 70 percent concentration. Mild steel (M.S.) is good for concentrations of from 93 to 98 percent.

(2) Fiberglass-reinforced polyester plastics (FRP) have been considered here However, there are fiberglass-reinforced epoxy resins available which are not considered in this table.

(3) FRP is good to 30 percent concentration. No organic solvents should be present. NACE has a graph for the compatibility of various metals for HCl use.

(4) FRP is good to 15 percent concentration.

(5) M.S. is good only to 25 C. 316 S.S. is recommended for service conditions above 25 C.

(6) FRP is good to about 50 percent concentration.

(7) M.S. is incompatible after about 5 percent concentration at 100 C.

(8) FRP is good to about 25 C.

(9) FRP is good to about 125 C.

(10) FRP is good for 95 percent concentration and 21 to 66 C.

(11) FRP is good from 10 to 35 C.

(12) Mild steel is incompatible for concentraitons below 100 percent.

(13) FRP is good for 10 percent concentration and 21 to 79.5 C.

(14) Mild steel is incompatible for concentrations below 100 percent.

(15) FRP is good at 10 to 32 C.

(16) Mild steel is good for 100 percent solvent to 100 C.

(17) NACE did not have data for gasoline; therefore, they were obtained from Petroleum Processing Handbook by W.F. Bland and R.L. Davidson (1967), pp 5-8.

(18) Stainless steel is good at 100 percent concentration.

(19) FRP is good for 5 percent concentration and 21 to 52 C.

TABLE B-1 (Continued)

(20) Mild steel is good for 100 percent concentration.

(21) FRP is good for only 100 percent concentration and 21 to 27 C; therefore, it is listed as incompatible.

(22) Mild steel is good only at 100 percent concentration and up to 100 C.

- Commonly used to store organic solvents and similar chemicals
- Limited corrosion resistance to certain wastes; therefore, extra thickness for corrosion allowances is often needed beyond the minimum thickness required for structural integrity when no lining or coating is used.
- Should not be used on contact with hydrochloric, phosphoric, or nitric acid.

B.1.2 Alloy Steels. Stainless steel is the most widely used alloy steel. At high temperatures it is highly resistant to corrosion and oxidation while maintaining considerable strength.

The following is a list of the types of alloy (stainless)steels and their characteristics:

- Austenitic steel (types 302, 304, 321, 326, 316, 317, and others)
  - Is the most highly resistant of stainless steels to many acids, including hot or cold nitric acid
  - Retains strength at temperatures as low as liquid helium
  - Responds well to severe stress at elevated temperatures
  - Subject to pitting with chloride ion
- Martensitic steel (types 405 through 410)
  - Is less corrosion resistant than austenitic steel
  - Used for mildly corrosive environments such as organic exposures

B.1.3 Concrete. This material is used predominantly in large open tanks and treatment basins. Several characteristics of concrete are listed below:

- Susceptible to freeze-thaw cracking and deterioration if not properly air entrained
- Subject to attack by nearly all sulfate salts if not made with sulfate-resistant cement

- Subject to attack by many chemicals including alum, chlorine, ferric chloride, sodium bisulfite, sulfuric acid, and sodium hydroxide (<20 percent).
- May be permeable to some liquids.

B.1.4 Plastics. In general, plastics have the following characteristics:

- Have excellent resistance to weak mineral acids and inorganic salt solutions
- Are good electrical and thermal insulators
- Do not corrode from chemical reactions
- Do not react to small changes in pH, minor impurities, or oxygen content.

Plastics are widely used for coating and lining materials and include polyethylene, chlorinated polyether, cellulose acetate butyrate, polyamide, polypropylene, polyester resin, and epoxy.

- Polyethylene is the least costly plastic that is commercially available. The carbon-filled grades are resistant to sunlight and weathering.
- Chlorinated polyether can withstand temperatures up to 225 F. It is not affected by dilute acids, alkalis, or salts. However, nitric acid over 25 percent in concentration, aromatics, and ketones cause degradation.
- Cellulose acetate butyrate is affected by chlorinated solvents, but not by dilute acids or alkalis.
- Polyamide (nylon) resists a number of organic solvents, but is not resistant to phenols, strong oxidizing agents, or mineral acids.
- Polypropylene has characteristics similar to those of polyethylene, and it can be used at temperatures greater than 250 F.
- General purpose polyester resins, when reinforced with fiberglass, have good strength and good chemical resistance, except to alkalis. Polyesters containing bisphenol are more alkali resistant. The temperature limit for using polyesters is about 200 F.

- Epoxy has good chemical resistance to non-oxidizing and weak acids. It is also resistant to weak alkaline solutions.

B.1.1.5 Rubber. Rubber and elastomers are also frequently used as coating and lining materials. In addition to natural rubber, a number of synthetic rubbers have been developed. While none have all the properties of natural rubber, some are superior for specific uses.

Natural rubber is resistant to dilute mineral acids, alkalis, and salts, but not to oxidizing agents, oils, benzene, and ketones. Hard rubber is made by adding 25 percent or more sulfur to natural or synthetic rubber, thus making it both hard and strong.

- Chloroprene or neoprene rubber is resistant to attack by ozone, sunlight, oils, gasoline, and aromatic or halogenated solvents.
- Styrene rubber has chemical resistance similar to natural rubber.
- Nitrile rubber is resistant to oils and solvents.
- Butyl rubber's resistance to dilute mineral acids and alkalis is exceptional; its resistance to concentrated acids, except nitric and sulfuric, is good.
- Silicone rubbers, also known as polysiloxanes, have outstanding resistance to high and low temperatures and to aliphatic solvents, oils, and greases.
- Chlorosulfonated polyethylene, known as hypalon, has outstanding resistance to most ozone and oxidizing agents except fuming nitric and sulfuric acids. Its oil resistance is good.
- Fluoroelastomer combines excellent chemical and high-temperature resistance.
- Polyvinyl chloride elastomer was developed to overcome some of the limitations of natural and synthetic rubbers. It has excellent resistance to mineral acids and petroleum oils.
- The cis-polybutadiene and cis-polyisoprene rubbers are almost duplicates of natural rubber.

- The newer ethylene-propylene rubbers have excellent resistance to heat and oxidation.

B.2 Mechanism of Deterioration of Materials

The purpose of this section is to orient the permit writer to the fact that the mechanism of deterioration differs for various classes of materials.

B.2.1 Metals

Corrosion is the primary process by which metals deteriorate. In the process of corrosion, the metal is reacted with a chemical in the liquid (or atmosphere) to form a non-metallic reaction product such as iron oxide or ferric chloride that has no strength and which is normally dissolved into the liquid. In some cases, intergranular corrosion may occur where the corrosion reaction occurs at the grain boundaries of the crystals in the metal matrix with a resultant loss of strength. If dissimilar metals are used in tank fabrication and assembly or if there are crevices or pits in the tank's surface, then galvanic-electrochemical reactions and, thus, corrosion of metals may occur.

Erosion is another form of deterioration that may occur with nearly all of the materials of construction. Erosion usually occurs because of a wearing action due to the presence of solids in a solution and high velocities at the metal or plastic surface. This wearing action will seldom occur in properly designed tanks. However, if erosion is combined with corrosion, the rate of metal removal may be very high.

B.2.2 Concrete

In some respects, the deterioration of concrete is similar to that of metals; chemical reactions are involved. However, several kinds of reactions may be involved. The formation of concrete involves the formation of crystalline mineral hydrates to bind the mixture of minerals and aggregates into an integral structure. The formation of concrete is referred to as hydraulic bonding (which is a misnomer). Nevertheless, the chemicals in a liquid may react with either the hydrate portion of the crystal, the minerals, or the aggregate. Concrete is very susceptible to attack by acids and aqueous solutions of sulfate salts. In some cases, concrete may be permeable to certain liquids even though NACE data indicates use of concrete is recommended.

B.2.3 Plastics and Rubbers

Although some reactions may occur between liquids and polymeric materials, their failure in service is seldom due to reactions. Nor do such materials normally fail due to complete dissolution--the dissolving of the polymer into the liquid. Such materials usually fail by absorption of liquids into the polymer with subsequent swelling and softening of the plastic resulting in the materials loss of strength. Occasionally, the material may become discolored or embrittled due to reactions. Polymers are also subject to stress cracking or crazing upon exposure to some organic chemicals.

B.3 Approach to Permitting

The permit writer must ascertain the effect of the waste proposed for storage upon the tank construction materials and the liner materials (if present). For further discussion of general compatibility between the waste proposed for storage and the tank materials, refer to:

- Compatibility of Wastes in Hazardous Waste Management Facilities: A Technical Resource Document
- Perry's Chemical Engineers' Handbook, which contains a specific section on corrosion
- Information published by the American Concrete Institute.

However, the National Association of Corrosion Engineers has prepared two books, Non-Metals Section--Corrosion Data Survey, fifth edition, NACE, Houston, Texas (1975) and Metals Section--Corrosion Data Survey, fifth edition, Houston, Texas (1974) that not only provide information about general compatibility, but also present numerous footnotes about the presence of non-uniform corrosion or the type of failure that can be expected. This latter type of information is essential to the permit writer in specifying the required frequency of inspection and to assure that appropriate inspection procedures are used to identify potential tank defects.

Other good sources of information are manufacturers of the materials of construction and occasionally manufacturers of tanks. Finally, one of the best sources of qualitative-type information that can be helpful in specifying inspection frequencies is the manufacturers of the chemical constitutents of hazardous wastes.

It is recommended that the applicant be required to provide such information at the time the permit application is made to fully support the applicant's selection of a suitable material of construction and suggested tank inspection frequency.

B.4 Gaskets, Liners, and Coatings

Many of the gasket, liner, and coating materials have been covered in sections B.2 through B.3. Nevertheless, some further information is presented for clarification.

B.4.1 Gaskets

Gaskets serve as fillers in static clearances that usually occur at concentric cylinders such as at flanges. Sealing is achieved by subjecting effective compression through bolts or other mechanical means. Improper gasket installation can easily result in a leak. Therefore, extra care should be given to select the proper type and material of construction for the gasket to ensure quality control during installation.

The most common types of gaskets are cylindrical or concentric, o-ring joints, and valve seats. Gasket selection should be based on site-specific objectives. During installation, care should be taken so that the gasket is properly placed in the flange and that it is not excessively compressed beyond the material's elastic limit. It should be noted that proper materials selection is imperative to avoid gasket deterioration, as a result of incompatibility between hazardous materials stored in the tank and the material of construction of the gasket.

Proper maintenance of gaskets will enhance the life and maximize performance. It is imperative that the manufacturers' recommendations for installation as well as maintenance be followed. In some cases, if deterioration is detected, the gasket should be immediately replaced.

Additional information about the important properties of gasket materials is presented in Table 5-24 of the Petroleum Processing Handbook (by W. F. Bland and R. L. Davidson, McGraw-Hill, New York, 1967). The Mark's Handbook (Mark's Standard Handbook for Mechanical Engineers, Eighth Edition, McGraw-Hill, New York) presents a discussion of packings and seals in Section 8 of the handbook.

B.4.2 Lining and Coating Materials

Tank deterioration, as a result of waste and tank material incompatibility, may cause tank failure. In situations where the waste is corrosive to the material of construction of the tank, some type of protection may be required. Either linings or coating materials are often used to protect the construction materials of a tank. The permit writer should review the waste type and tank materials of construction to assure that the tank is protected against corrosion. Linings and coatings are defined below:

- "Linings" are materials attached to the inner shell of a tank. Common lining materials include glass, rubber, plastic, lead, tar, and brick.
- "Coatings" are thin films of natural or synthetic organic material, either sprayed or brushed on the inside surface of the tank to reduce internal/external deterioration.

Table B-2. IMPORTANT PROPERTIES OF GASKET MATERIALS

RESERVED PENDING RECEIPT OF PERMISSION TO REPRODUCE.
TABLE 5-24 OF "PETROLEUM PROCESSING HANDBOOK".

TABLE B-2. (CONTINUED)

RESERVED PENDING RECEIPT OF PERMISSION TO REPRODUCE. TABLE 5-24 of "PETROLEUM PROCESSING HANDBOOK".

TABLE B-2 (CONTINUED)

RESERVED PENDING RECEIPT OF PERMISSION TO REPRODUCE.

TABLE 5-24 OF "PETROLEUM PROCESSING HANDBOOK".